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INNOVATIVE TECHNOLOGY EVALUATION (ITE) OF MCCORMICK AND BAXTER PORTLAND, OREGON

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FOR
OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY

GEOENGINEERS

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INNOVATIVE TECHNOLOGY EVALUATION (ITE) OF McCORMICK AND BAXTER PORTLAND, OR

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LIST OF ACRONYMS

AOP	Advanced Oxidation Processes
bgs	Below Ground Surface
BNSF	Burlington Northern Santa Fe
CSM	Conceptual Site Model
DEQ	Oregon Department of Environmental Quality
EPA	United States Environmental Protection Agency
ERH	Electrical Resistive Heating
ESD	Explanation of Significant Difference
F	Fahrenheit
FWDA	Former Waste Disposal Area
gpm	Gallons per Minute
GAC	Granular Activated Carbon
ISCO	In-situ Chemical Oxidation
ITE	Innovative Technology Evaluation
K	Hydraulic Conductivity
µg/kg	Micrograms per Kilogram
µg/L	Micrograms per Liter
mg/L	Milligrams per Liter
ROI	Radius of Influence
LNAPL	Light Nonaqueous Phase Liquid
DNAPL	Dense Nonaqueous Phase Liquid
M&B	McCormick and Baxter
NPDES	National Pollution Discharge Elimination System
LPAH	Low Molecular Weight Polynuclear Aromatic Hydrocarbons
HPAH	High Molecular Weight Polynuclear Aromatic Hydrocarbons
PCP	Pentachlorophenol
ROD	Record of Decision
USCOE	United States Army Corps of Engineers
RCRA	Resource Conservation Recovery Act
TFA	Tank Farm Area

1.0 INTRODUCTION

The Innovative Technology Evaluation (ITE) for the McCormick and Baxter site (M&B site) in Portland, Oregon (Figure 1) is intended to describe the development and evaluation of innovative technologies that may be used to enhance the recovery of non-aqueous phase liquids (NAPL). The ITE was completed by GeoEngineers, Inc. and Aquifer Solutions, with substantial contribution from the Oregon Department of Environmental Quality (DEQ) Orphan Site Program and United States Army Corps of Engineers (USCOE) Seattle District. In October 2005, the ITE was submitted in draft form to the Environmental Protection Agency and their partners for review and comment. Comments received from the partners were either incorporated into the final ITE, or addressed in the comment response letter prepared by DEQ. The comment response letter is included as an appendix to the ITE. The ITE was prepared for the Oregon Department of Environmental Quality (DEQ) under Task 5 of Environmental Services Task Order 72-03-15.

The groundwater remedy for the site, as specified in the 1996 record of decision (ROD), required an evaluation by pilot testing of innovative technologies, such as surfactant flushing, to increase the effectiveness and the rate of NAPL removal. This requirement was modified in an Explanation of Significant Difference (ESD) issued in 2002 by DEQ and EPA. The ESD states that this provision of the groundwater remedy has not yet been implemented because NAPL accumulations on site appear to be decreasing and there are concerns that, in the absence of containment, the pilot tests could mobilize NAPL resulting in increased discharge to the Willamette River. The ESD further states that pilot testing of innovative technologies and enhancement of the existing recovery system would be considered after the barrier wall has been implemented and NAPL discharge is contained.

This ITE draws heavily on site information presented in the draft Remedial Action Conceptual Site Model Report (DEQ, 2005) for site historical and investigative background information, and also for the presentation and technical discussion of site-specific NAPL physical properties and mobility testing. This information is presented in summary form in Section 2.0 and applied throughout the document through collaboration and input from DEQ and additional NAPL mobility and depletion time calculations by the USACE and DEQ.

1.1 PROJECT OBJECTIVES

The objectives of the Innovative Technology Evaluation are to:

- Assess expected NAPL recovery performance of innovative, and current recovery technologies;
- Review, evaluate and compare several innovative NAPL recovery technologies;
- Evaluate whether implementation of the innovative technologies are feasible and would reduce the potential of NAPL migration into the river at the M&B site with the current remedy in place (the barrier wall, sediment and soil caps); and
- Complete a cost benefit analysis for each retained innovative technology and variations of the current condition.

The ITE was conducted to assess whether the application of an innovative technology for NAPL recovery or destruction or continued single-phase extraction, in combination with other site remedies, will result in additional net benefit to human health and the environment.

1.2 SCOPE OF SERVICES

GeoEngineers and Aquifer Solutions completed the ITE in general accordance with the ITE Work Plan, dated April 20, 2005. The scope of services was completed in three phases.

- Phase1 – Technology Screening;

- Phase 2 – Detailed Feasibility Evaluation; and
- Phase 3 – Technology End Points and Cost-Benefit Analysis.

1.2.1 Phase 1 – Technology Screening

This technology screening step was conducted as part of the ITE Work Plan (GeoEngineers and Aquifer Solutions, 2005). The results of the Phase I technology screening were discussed with the DEQ and Partners in a teleconference on March 31, 2005, and the comments were incorporated into the final work plan.

Phase I of the ITE identified a range of innovative technologies with potential to further reduce the mobility of NAPL. These technologies were screened based on their ability to achieve the objective of further reducing the potential for NAPL migration to the Willamette River if deployed in concert with the remainder of the remedy (subsurface barrier wall, upland soil cap and sediment cap).

The initial technology screening is presented in the ITE Work Plan (GeoEngineers and Aquifer Solutions, 2005). Table 1 contains the initial technology screening. The following technologies were evaluated during the initial technology screening:

- Dual-phase extraction or bioslurping;
- In situ bioremediation using hydrogen peroxide;
- Cold water flooding;
- Hot water flooding;
- Surfactant or co solvent flushing;
- In situ chemical oxidation using ozone;
- Conductive heating or in situ thermal desorption;
- Electrical resistive heating;
- Steam injection; and
- Dynamic underground stripping (steam injection & resistive heating).

A list of other creosote remediation sites where no innovative technologies have been used to date was also provided for context. Table 1 briefly documents the reason(s) for eliminating, or retaining, a particular technology from further consideration.

This screening was performed to qualitatively reduce the number of potentially applicable technologies to allow the ITE to develop more refined alternatives for the most promising technologies. Technologies were eliminated from consideration if found to be impractical for wood preservatives, because of site conditions, or if there was a very high likelihood for a particular technology to cause increased discharge of NAPL to the Willamette River. The technologies were reviewed by the EPA and their partners prior to determining the final technologies to retain for the detailed analysis. Based on the initial technology screening, the team identified four technologies that were applicable to the physical and chemical conditions at the site, and retained them for additional consideration. The retained technologies are:

- Cold water flooding;
- Hot water flooding;
- In-situ chemical oxidation; and

- Electrical resistive heating.

1.2.2 Phase 2 – Detailed Feasibility Evaluation

For the detailed evaluation discussed in this document, the ITE defined and described each retained technology. A deployment configuration was developed for each alternative and used as a base case for the comparison of each of the retained technologies to one another. A unit cell approach that is described in Section 4.1 was developed to evaluate each technology on a range of scales, i.e. pilot scale to full-scale. Due to the limited site-specific data available for the performance of many design variables, this approach was deemed to balance uncertainties in each technology and a range of values was provided (see Table 2 to 5) for most cost variables. Conceptually one unit cell could represent a pilot test while the maximum number of unit cells would treat each focus area, see Section 4.1, completely. The user of the ITE can use the information contained herein to evaluate numerous configurations of each technology within each focus area given the information contained within the ITE, however an exhaustive analysis and description of every possibility is beyond the resources and scope of the ITE.

Each technology was generally evaluated with respect to the following five feasibility criteria.

- **Effectiveness**
  - Ability of the technology to recover or destroy NAPL; and
  - Length of time until the technology could be fully operational, if deployed at the site.
- **Long-term Reliability**
  - Nature, degree and certainties or uncertainties of any necessary long-term management (e.g., operation, maintenance and monitoring).
- **Implementability**
  - Practical, technical and legal difficulties and unknowns associated with the construction and implementation of the technology;
  - Ability to monitor the effectiveness of the technology; consistency with federal, state and local requirements; availability of necessary services, materials, equipment, and specialists; and potential scheduling delays; and
  - Evaluation of the pros and cons associated with pilot testing the innovative NAPL recovery technology(ies).
- **Implementation Threat**
  - Potential impacts on workers, the environment and the public during implementation of the technology and the effectiveness and reliability of protective or mitigative measures;
  - Potential impacts on existing remedies (barrier wall, soil cap and sediment cap) during implementation of the technology and the effectiveness and reliability of protective or mitigative measures; and
  - Length of time until the technology could be decommissioned (i.e., when treatment is no longer necessary).
- **Cost**
  - Semi-quantitative presentation of costs associated with engineering design, construction, annual operation and maintenance, and decommissioning.

Each retained innovative technology was compared using a head-to-head, comparative ranking process. The most promising technologies were identified based on the ranking process and retained for further consideration and input from the McCormick and Baxter Project Team.

1.2.3 Phase 3 – Technology End Points and Cost-Benefit Analysis

The most feasible innovative technology(ies) were further evaluated to assess whether, or to what extent, the technology would significantly reduce the potential for NAPL migration to the Willamette River if deployed in concert with the existing remedies (i.e., subsurface barrier wall, upland soil cap and sediment cap). Additionally, the existing remedy both with and without an enhancement of the single-phase extraction approach were also included in this evaluation.

As part of this evaluation, a semi-quantitative estimate of mass removal and subsequent mobility reduction was developed for the most feasible technology(ies). This portion of the evaluation builds on the product volume and mobility work completed in the draft updated CSM (DEQ, 2005). Specifically, we estimated the anticipated NAPL saturation reduction and/or mobility reduction efficiency based on site conditions, NAPL characteristics, case-studies in the literature and our experience on similar sites. Using the CSM NAPL mobility calculations, we assessed the potential affects of the most feasible technologies on the volume of NAPL, mobility, and expected life of the granular organoclay component of the sediment cap.

2.0 SITE BACKGROUND

The McCormick and Baxter site is located on the eastern waterfront of the Willamette River, in Portland, Oregon (Figure 1). The site includes 41 acres of land and 23 acres of contaminated sediments beneath the Willamette River. With the exception of the activities associated with the ongoing remedial actions, the site is vacant. A Burlington Northern Santa Fe (BNSF) railroad corridor, located on a 25 to 30 foot high elevated embankment, crosses the northwest portion of the site, and a Union Pacific railroad corridor crosses the north portion of the site.

The historical layout of the site is shown on Figure 2. Treating and preservative storage (tank farm area) were primarily focused in the central portion of the facility. Treated product storage was primarily on the northern portion of the site, adjacent to the BNSF rail corridor. Two former waste disposal areas were historically utilized in the southeast and northeast portions of the site.

This section is intended to provide the reader with sufficient background information to understand the context of the ITE. The reader is referred to the draft Remedial Action Conceptual Site Model report (DEQ, 2005) for detailed information with regard to site background and history.

2.1 SITE HISTORY

The McCormick and Baxter property was largely created through the fill of lowlands and floodplain with dredged materials in the early 1900s. At that time, a sawmill operated on the southeast portion of the facility. McCormick and Baxter Creosoting Company was founded in 1944 to produce treated wood products (lumber, pilings, railroad ties, etc.) during World War II. The facility operated for just over 40 years, until 1991.

Through the period of operation, various wood treatment processes have been utilized at the site, including coal-tar based creosote treatment, oil-based pentachlorophenol (PCP) treatment, water-based chrome treatment, and Cellon (a mixture of PCP, liquid butane, and isopropyl ether). Creosote and other treatment products were delivered to the site by rail car, truck, and ship.

Historically, wastewater and cooling water were discharged from the site directly to the Willamette River (from 1945 to 1969). Prior to 1971, oily waste and storm water were discharged to a waste disposal trench in the southeast portion of the site. In 1971, an evaporator was installed to treat process wastewater. Non-contact cooling water continued to be discharged to the Willamette River, and other wastewater was treated and discharged under a National Pollution Discharge Elimination System (NPDES) permit. Other unpermitted discharges existed for a period of time, however these discharges have been discontinued since DEQ's site stabilization activities were initiated.

Two major releases have reportedly occurred at the site: a 50,000-gallon release in the tank farm in approximately 1950 and a large release (unrecorded quantity) of creosote from a tank car near the tank farm in 1956. Additionally, waste oil containing creosote and PCP were applied at the site for dust control purposes between 1950 and 1965.

2.2 SUMMARY OF CLEANUP ACTIVITIES COMPLETED OR UNDERWAY

Beginning in 1992, DEQ implemented a number of removal measures, including plant demolition, sludge and soil removals, and extraction of creosote from the groundwater aquifers. Creosote is currently being recovered manually. Approximately 5,500 gallons have been recovered since 1989.

Implementation of the soil remedy began in March 1999 with the removal of 33,000 tons of highly contaminated soil and debris. The soil remedy was completed in September 2005 by capping the entire site, including a subsurface barrier wall area, with a combination RCRA-cap and earthen cover. Within the barrier wall where the most highly contaminated subsurface soils are still present at the site, a RCRA-cap was placed over 15-acres and an evapotranspiration cap was placed over the 3.1 acres of Riparian area within the barrier wall. The remainder of the cap (outside of the barrier wall areas) consists of 2 feet of clean, imported topsoil. The cap is designed to 1) prevent infiltration of rainwater to contaminated areas within the barrier wall, 2) remove the direct-contact pathway to surface soils across the entire site, and 3) prevent surface water from contacting contaminated surface soils and subsequent transport to the river. The entire cap will be planted with native grasses.

As a component of the groundwater remedy, an impermeable subsurface barrier wall was installed around 18 acres of the site in 2003. The subsurface barrier wall contains a large portion of the primary source areas of groundwater contamination and should minimize horizontal seepage of creosote into the Willamette River. A protective cap was placed over areas of contaminated river sediments posing an unacceptable threat to human health and the environment. A sorptive cap material, granular organoclay, was placed over the known NAPL seep areas. DEQ completed the construction of the sediment cap in two phases: July through November 2004 and August through September 2005.

Currently, passive NAPL extraction is occurring in 5 wells outside of the barrier wall. A temporary automated extraction system was deployed for wells outside of the barrier wall during the fall of 2004. Operation of this system ceased in January 2005 – NAPL is currently extracted manually. Monthly NAPL recovery ranges from 30 to 60 gallons, and has recently increased coincident with installation of the barrier wall, increased recovery efforts, and/or general site activity associated with construction of the barrier wall and sediment cap.

2.3 SITE GEOLOGIC AND HYDROLOGIC SETTING

2.3.1 Site Geology

The McCormick & Baxter site is located near the western edge of the Portland Basin (Figure 1), which is a northwest-southeast-trending sediment-filled structural basin within the Willamette River Lowland Aquifer system (Beeson, et. al., 1985; Beeson, 1991). The ancestral Willamette River cut a channel between the bluff at the northeast boundary of the site and the base of the Tualatin Mountains to the southwest. Over the last 13,000 years these ancestral river channels filled with Recent Alluvium causing river base levels to rise. The McCormick &

Baxter site is situated on a terrace of hydraulic sand fill located within the flood plain of the Willamette River. The dredged materials were placed sometime in the early 1900s.

As described in the CSM, the geologic units beneath the McCormick & Baxter site consist of the following, from oldest to youngest:

- Columbia River Basalt Group. The Columbia River Basalt Group consists of a series of Miocene lava flows. The flows are typically black to dark gray, fine- to medium-grain aphyric to sparsely phyric basalt, and commonly exhibit columnar and/or irregular jointing (Gannett and Caldwell, 1998);
- Sandy River Mudstone. The Sandy River mudstone is a massive siltstone with thin sand interbeds (Swanson et. Al., 1993). Published geologic reports, maps, and cross-sections suggest that the Sandy River mudstone is present at a depth of approximately 200 to 300 feet bgs at the site;
- Troutdale Formation. The Troutdale Formation, which underlies the site, consists of a fluvial conglomerate with quartzite and granite clasts exotic to the region. The formation was scoured by the ancestral Willamette River;
- Catastrophic Flood Deposits. Catastrophic flood deposits consisting of gravels and sands form the bluff along the northeast edge of the site;
- Recent Alluvium. Deposits of silts and sands to a minimum of 180 feet bgs at MW-23d near the center of the site suggest infilling of the ancestral channel by Recent Alluvium. Alluvial sand and silt deposits were exposed at the surface before placement of hydraulic dredge fill. The sand and silt were presumably deposited as overbank alluvium near the bluff and as channel alluvium near the current river channel; and
- Hydraulic Dredge Fill. Fill was placed on the existing flood plain at the site in the early. The fill consists of 20 to 30 feet of fine- to medium-grain sand with little or little silt. A silt layer found at a depth of approximately 30 feet across portions of the site is interpreted to represent the former flood plain surface. In parts of the site, particularly near the TFA and in the south corner, the fill includes bark, sawdust, wood chips, and fresh wood layers up to 20 feet thick.

2.3.2 Site Hydrogeology

The geologic units described above are grouped into three water-bearing zones (shallow, intermediate, and deep). The three water-bearing zones are interconnected to varying degrees depending on their location within the site. Brief descriptions of the zones are presented below.

Shallow Water-Bearing Zone. The shallow water-bearing zone consists of dredge fill sand and wood debris. The alluvial sands and silts of the Recent Alluvium define the base of the shallow water-bearing zone (20 to 30 feet below ground surface). The shallow zone acts as an unconfined aquifer that, except within the barrier wall area and close to the bluff away from the river, is in hydraulic connection with the river. Groundwater elevations within the barrier wall have ranged from approximately 3 to 15 feet NGVD, depending on the well location and on the season.

Intermediate Water-Bearing Zone. The intermediate water-bearing zone ranges up to 50 feet thick and primarily consists of the Recent Alluvium. This zone can be found beneath a silt unit over most of the site. In the center of the site (TFA vicinity), the intermediate water-bearing zone is replaced by a thick silt unit. Discontinuous silt layers exist in the FWDA, leaving the intermediate water-bearing zone hydraulically connected to the shallow water-bearing zone.

Deep Water Bearing Zone. The deep water-bearing zone is present across the entire site. It consists of alluvial sands, the Troutdale Formation, and within the scoured zone of the Troutdale formation, the sand infill. Along the river margin, the deep water-bearing zone is in alluvial sands and is directly connected with the intermediate water-bearing zone and, to a lesser extent, the shallow water-bearing zone. Near the center of the site, the deep water-bearing zone is separated from the shallow zone by more than 100 feet of low-permeability silt. Near the bluff, the deep water-bearing zone is made up of the gravel and sands of the Troutdale Formation and Catastrophic Flood Deposits. This zone is estimated to reach a thickness of as much as 150 feet.

2.3.3 Willamette River Stages and Hydrological Influences

As described in the CSM, water levels in the Willamette River are influenced by many factors including seasonal precipitation, storage and release from multiple reservoirs, tidal fluctuations and the stage in the Columbia River. Lowest water levels typically occur between September and early November, prior to the winter rainy season. These seasonal fluctuations average approximately 10 to 15 feet, however more significant variation has been observed. Winter river stage is relatively high, but variable due to short term changes in precipitations levels. Also, May through June corresponds to another period of high water in the Willamette as high-water stage in the Columbia slows flow in the Willamette. Based on hydrographs presented in the draft updated CSM (DEQ, 2005), the intermediate and deep water bearing zones are in direct communication with the river.

3.0 FOCUS AREAS AND NAPL PROPERTIES

As described in Section 2.2, DEQ has been implementing removal measures and/or remedial actions at the site since the early 1990s. The actions are comprehensive in nature and together address exposure pathways as follows:

- Transport and exposure potential from residual source materials in soil have been addressed through a combination of soil removal activities and the soil cap;
- Transport and exposure potential to groundwater from NAPL and dissolved-phase constituents has largely been addressed through a combination of NAPL recovery (historic and ongoing), and construction of the subsurface barrier wall and soil cap; and
- Transport and exposure potential to river sediments that contain contaminants above protective levels have been addressed by the construction of a sediment cap augmented with granular organoclay in areas where active NAPL seeping was present.

The extent of each of these remedial actions is shown on Figure 3. The cumulative effect of these actions incorporates the majority of the contamination sources and contaminated media at the site (DEQ, 2005). However, there are two areas with observed mobile NAPL occurrence outside of the barrier wall: 1) down gradient of the former waste disposal area (FWDA) and 2) located outside of former tank farm area (TFA). These are areas where active seeping was observed post-barrier wall construction, prior to sediment cap emplacement. In these areas, 1 foot of granular organoclay was emplaced within the sediment cap to sorb the NAPL prior to reaching the river. The granular organoclay is expected to have the capacity to sorb the remaining mobile NAPL outside of the barrier wall (DEQ, 2005). However, as there is uncertainty associated with the mobility and cap life calculations and the characterization of the seep locations, these are the focus areas of this ITE.

The ITE did not focus on NAPL recovery within the barrier wall, as the barrier wall is expected to provide protection from the NAPL migrating laterally to the River and it was shown that there is little risk of mobile NAPL overtopping the barrier wall (DEQ, 2005).

3.1 FORMER WASTE DISPOSAL AREA (FWDA)

Historically, seeps to the river have been observed downgradient of the FWDA along a 400 foot length of Willamette River shoreline and a 250 foot wide portion of Willamette Cove. Post-barrier wall investigations found that the Willamette River FWDA seep area was depleted of mobile NAPL. Only odor and discoloration were observed in soil borings advanced along the shoreline (DEQ, 2005). Therefore, the focus of the ITE, down gradient of the FWDA, is solely on the Willamette Cove seep (see Figure 4).

The subsurface between the barrier wall and Willamette Cove is underlain by alluvial sands (Figure 5) with a gravel zone coincidental with the water table. Several discontinuous silt lenses are also present at various horizons. The gravel zone appears to provide a preferential pathway for groundwater and LNAPL migration to Willamette Cove. The lateral extent of LNAPL in this area corresponds to an area approximately 250 feet square (Figure 5). LNAPL was observed seeping into the Willamette River after installation of the barrier wall. A 1 foot thick patch of granular organoclay was placed in the location where NAPL was observed seeping into Willamette Cove (Figure 4). The western portion of this area is largely occupied by the BNSF Railroad Trestle and a 20 foot wide sewer easement.

3.2 FORMER TANK FARM AREA (TFA)

The portion of the TFA located outside the barrier wall is shown on Figure 6. This area encompasses a 100 foot wide by 300 foot long section of Willamette River shoreline. This area is comprised largely of unobstructed shoreline. An interceptor trench was excavated in this area in 1993 to capture NAPL migrating towards the river. NAPL seeps were observed and documented in this area in 2002 and 2003 and again during the post barrier wall investigation. Free-oil was not recovered from the trench before its removal in 2003 during installation of the barrier wall.

The subsurface in this area is comprised largely of alluvial sands with some discontinuous silt lenses (Figure 7). A laterally extensive silt layer is present at approximately -5 feet NGVD, and locally it appears to restrict vertical migration of NAPL (Figure 7) and also serves as a horizon where NAPL can migrate laterally towards the Willamette River. During the 2004 investigation (post-barrier wall) mobile NAPL was observed at saturations up to 12.5% overlying the silt layer at the mudline interface (DEQ, 2005). This area was capped with 1 foot of granular organoclay in the area shown in Figure 6.

3.3 NAPL PROPERTIES

The summary of the chemical composition and physical properties of NAPL at the McCormick and Baxter site are taken from Section 4 of the draft Updated CSM and Summary of Remedy Implementation Report (DEQ, 2005). As described by DEQ (2005), the chemical composition of the NAPL can be broken down as follows:

- PAH content ranges from 8 to 20 percent by weight in the FWDA and 7 to 36 percent in the TFA;
- The proportion of lighter weight PAH may be decreasing as compared to heavier weight PAH;
- Pentachlorophenol occurs primarily in the FWDA and is less common in the TFA; and
- Aromatic compounds tend to dominate over aliphatics.

The following sections summarize the physical properties of the NAPL as a basis for evaluation of innovative remediation technologies for the reduction of NAPL mobility.

3.3.1 NAPL/Water/Soil Wettability and Interfacial Tensions

The NAPL/water wettability of soil describes the tendency of either fluid to coat the soil grains preferentially over the other. The wettability of soil is dependent of the soil surface chemistry, electrostatics, and fluid wetting history. In general, most soils which have not been exposed to petroleum liquids are water wet - meaning water will coat the soil grains and NAPL will be restricted to the central portion of the pore spaces by capillary forces. An oil wet soil results from exposure to petroleum compounds by natural or anthropogenic processes.

Overall, McCormick and Baxter site soils are moderately oil wet with measurements ranging from neutral to moderately oil wet. This may be the result of the exposure duration of NAPL in the subsurface and the chemical characteristics of the wood preservatives used at the site. In general, strongly oil or water wet soils will tend to retain NAPL more strongly than soils with neutral wettability.

The interfacial tension between fluids and the wettability of the soil affect the capillary pressure influence on NAPL movement in porous media. The interfacial tension is a measure between the difference in molecular forces within each fluid as measured across the interface between the fluids while wettability considers the interactions between the soil surface and fluid.

The interfacial tension of air and NAPL ranged from 32 to 39 dynes per centimeter. The interfacial tension of water and NAPL ranged from 4.1 to 75.4 dynes per centimeter and may have been influenced by the dissolved NAPL constituents in the water sample that was used.

These results suggest that the media is more NAPL wet than water wet and capillary forces may vary over an order of magnitude. This suggests that NAPL migration may occur at low saturations and moderate specific gravities as a result of pressure gradients.

3.3.2 Specific Gravity of NAPL

The specific gravity of the NAPL is the ratio of the density of the NAPL to the density of water. Density is the ratio of the weight of a volume of fluid to the volume of the fluid. Specific gravity values greater than one suggest that the fluid will sink by gravitational forces thru water whereas a fluid with a specific gravity less than one would tend to float on water.

The specific gravity measurements range from 0.964 to 1.0941 for NAPL samples from the site. In general, the samples analyzed from the FWDA had a specific gravity less than 1 or very close to 1 while samples from the TFA have specific gravities greater than one.

The specific gravity, and density, of the NAPL samples decreased with increasing temperature. This suggests that if heat is applied to the subsurface that the NAPL will not tend to sink due to gravitational forces.

3.3.3 Viscosity

The viscosity is a measure of the molecular friction within a fluid that produces the fluid's ability to flow. The viscosity of the fluid affects the fluid's relative permeability to that of water. The viscosity of the McCormick and Baxter NAPLs are 18 to 45 times that of water at ambient temperatures (Table 4-6 DEQ, 2005). When a fluid is heated the viscosity tends to decrease significantly. For example, when groundwater was heated to 130 degrees F the viscosity halved whereas when the NAPL was heated to 120 degrees F the viscosity decreased four to five times. This suggests that heating will increase the relative permeability of NAPL more than water.

3.3.4 Free Product Mobility Testing

Free product mobility testing was performed to evaluate porosity, density, and residual NAPL saturations among other parameters. Porosity values were high ranging from 38 to 61 percent. Bulk density measurements ranged from 1.2 to 1.6 grams per cubic centimeter (g/cm^3) for sands and 0.9 to 1.2 g/cm^3 for silts.

Initial NAPL saturations ranged from 0.1 to 16 percent in the 15 cores collected from areas where the highest NAPL saturations were expected. Residual saturations measurements for the 2 cores where the post-centrifugation saturation was lower than the initial saturation were 7.3 and 12.6 percent. The initial water saturations ranged from 38.4% to 99.9%.

Additional testing was performed to evaluate the capillary pressure and relative permeability behavior of samples from the McCormick and Baxter site. All samples for these additional tests were sands. The porosity values ranged from 35 to 49 percent during capillary pressure tests and 31 to 45 percent for relative permeability samples. Residual oil saturations varied from 1 to 14 percent for capillary pressure tests and 13 to 63 percent for the drainage condition under relative permeability testing. Pressure saturation and relative permeability curves are provided in the draft Remedial Action Conceptual Site Model (DEQ, 2005) as Figures 4-3 to 4-8 and 4-9 to 4-14, respectively.

4.0 PHASE 2 – DETAILED FEASIBILITY EVALUATION

This section describes the approach that was implemented for the Phase 2 feasibility evaluation, descriptions and deployment scenarios for each technology, and the comparative evaluation.

4.1 INNOVATIVE TECHNOLOGY EVALUATION APPROACH

The ITE approach was developed by considering the site-specific information available concerning NAPL properties, the site conceptual model, and site logistical issues. The four innovative technologies evaluated are in situ treatment processes that are inherently subject to more variations in performance due to subsurface heterogeneity and variability than ex situ, above ground, treatment processes. In situ remediation design is commonly supported by bench and field pilot tests and more interactive in nature than design of ex situ treatment processes. Therefore, in the absence of site-specific bench tests or pilot tests, an approach that seeks to balance the known and unknown factors was developed.

Conceptual deployment scenarios were developed as a basis for comparison of the alternatives. The conceptual designs were developed by evaluating the available site-specific information, considering the literature and other applications of these technologies to creosote sites, and input from contractors that have expertise in individual technologies.

4.1.1 Unit Cell

A unit cell approach was used to allow the user of the ITE to evaluate the cost and potential durations for each technology applied over an area of interest at the site. The dimensions of the unit cells were established for each technology based on the conceptual design parameters and the site-specific information, where available. The unit cell represents a minimum economically viable full-scale implementation area. The minimum unit cell dimensions were selected based on hydrogeologic conditions and treatment technology factors while balancing capital costs economies of scale to maintain maximum utility of the unit cell approach. This balance suggests that pilot test treatment cost (cost per cubic yard of treated soil) may be more than the treatment cost for a single unit cell, while the full-scale deployment of numerous unit cells may have a treatment cost that is less than the sum of the unit treatment cost for numerous unit cells.

4.1.2 Range of Variables

In the absence of site specific bench and field pilot testing, the ITE identified several variables that could not be established with a high degree of certainty while other variables were estimated to within an acceptable range of uncertainty. The variables that are subject to a broad range of values and that have a significant affect on the performance and cost of each technology were evaluated at minimum, maximum, and expected values. This approach provides flexibility to refine values as additional information becomes available and to identify the data gaps with respect to the innovative technologies at this time.

The following variables were assessed with respect to minimum, maximum, and expected values for each technology:

- NAPL removal efficiency;
- Unit cells per focus area;
- Durations;
- Labor estimates;
- Capital costs; and
- Operating costs.

Tables 2 to 5 provide the ranges of variables used by technology as well as the unit cell dimensions, well configurations, and design parameters.

5.0 DESCRIPTION OF RETAINED TECHNOLOGIES

Along with the four innovative technologies that were retained for additional consideration, the current remedial approach, both with and without single-phase NAPL recovery, are also considered. The retained innovative technologies are:

- Cold water flooding;
- Hot water flooding;
- In-situ chemical oxidation; and
- Electrical resistive heating.

5.1 CURRENT CONDITION, DISCONTINUE EXTRACTION

This scenario considers that NAPL extraction would not occur as part of the remedy. The remedy in place consists of the following components:

- Site demolition;
- Soil hot spot removal;
- NAPL extraction (greater than 5,500 gallons of NAPL have been removed to date);
- Fully-encompassing barrier wall surrounding the major upland source areas;
- Soil cap; and
- Sediment cap augmented with granular organoclay in the active NAPL seep areas.

Under this scenario, weekly NAPL extraction would be discontinued and if NAPL were to break through the sediment cap, the sediment cap would need to be repaired. Should NAPL breakthrough occur, and depending on the severity of the breakthrough, a repair could be completed by either placing an organoclay blanket over the sediment cap breach or by placing a layer of granular organoclay over the sediment cap breach.

5.2 CURRENT CONDITION WITH SINGLE-PHASE EXTRACTION

Various NAPL extraction approaches have been implemented at the site since 1989 (CSM Section 2.2.2, 2005). The approaches have included manual extraction of NAPL-only, total fluids extraction, automated skimming, an interceptor trench, and a variety of above ground unit processes. Above ground treatment of NAPL-groundwater mixtures (most recently using oil-water separators, anthracite/clay filter, aqueous phase GAC, and a metals treatment unit) has proven expensive and difficult to operate. The automated treatment systems were shut-down in September of 2000. Since that time a protocol of weekly gauging of wells with manual single-phase extraction (NAPL-only) when product thickness exceed 0.4 feet has improved the cost effectiveness of NAPL recovery operations.

Generally, the extraction wells that are used for NAPL recovery were originally intended for monitoring, so, although they are placed where NAPL saturations are high, they are not necessarily constructed to optimize NAPL extraction. Manual extraction activities have resulted in NAPL recovery rates of up to 60 gallons per month until the barrier wall was installed. NAPL recovery has increased since the completion of the barrier wall to an average of 80 gallons per month. With respect to the ITE focus areas, approximately 11 gallons of LNAPL per month are extracted from Flowpath1 which is LNAPL outside the barrier wall in the FWDA migrating to Willamette Cove.

The current NAPL extraction approach could be enhanced to improve the effectiveness and efficiency of NAPL recovery through:

- Installing recovery-specific wells outside the barrier wall - The majority of the wells used for NAPL recovery were designed as monitoring wells. Recovery wells targeted to the specific zones of NAPL occurrence and with optimal well construction (e.g., coarse filter pack and wire-wrapped well screens) and development (e.g., jetting) techniques to maximize the capillary connection of the wells with the formation would improve NAPL recovery.
- Using pumps that minimize disturbance of the NAPL-water mixture - The single largest factor that contributes to difficulty with separation of NAPL and groundwater is emulsification of the NAPL-water mixture. This can be minimized through pump selection and detailed design of the conveyance system. Positive displacement pumps such as bladder, piston, or smooth disc impeller centrifugal pumps are the best options available to minimize shear. Bladder or piston pumps are more appropriate than smooth disc impeller pumps for the McCormick and Baxter site due to limits on the net positive suction head of the former. If gas actuated pumps are used it is important that gas supply and exhaust do not contact the NAPL-groundwater mixture otherwise emulsification will occur. Additional care should be taken to select a conveyance system that minimizes constrictions and turbulence in the event that NAPL and groundwater are extracted concurrently.
- Assisting flow towards the extraction wells – The NAPL recovery efficiency of extraction only approaches may be limited by the maintenance of a continuous flow path of NAPL to the recovery well, the gradient towards the recovery well, the localized stratigraphy, and NAPL viscosity and density. Techniques that assist flow of NAPL into recovery wells include dual recovery of groundwater and NAPL by separate pumps to increase the gradient towards the recovery wells, or low continuous pumping of NAPL at a flow rate equal to the rate that NAPL enters the well to maintain flow paths to the extraction wells and recover as much as possible using single phase extraction. These approaches tend to improve LNAPL recovery more than DNAPL recovery, however both LNAPL and DNAPL recovery may be improved by increasing NAPL or hydraulic gradients toward extraction systems.

5.3 Innovative Technology 1: Cold Water Flooding

Cold water flooding increases hydraulic gradients and effectively "pushes and pulls" NAPL toward a recovery and collection system. Through simultaneous injection of treated groundwater and extraction of groundwater, hydraulic gradients are increased, NAPL is mobilized, and flow occurs faster and to lower saturations than under natural conditions.

Cold water flooding utilizes multiple injection-extraction well pairs and configurations. The induced hydraulic gradients must exceed capillary and gravitational forces in order to mobilize NAPL above residual saturation. The soil at the McCormick and Baxter is generally neutral with respect to oil/water wetness (DEQ, 2005). The specific gravity of the NAPL is close to that of water (DEQ, 2005). Together this suggests that NAPL mobility will not be restricted by capillary or gravitational forces. As a result, cold water flooding was deemed promising during the initial technology screening.

The operational duration for cold water flooding may range from 24 to 60 months with an expected duration of 48 months. Cold water flooding would require 4 to 6-inch pressure injection wells and 4-inch extraction wells with submersible pumps. Bladder pumps would be preferred to minimize shearing of the extracted fluids however adequate flow rates may not be achieved (piston pumps were considered but have a lower flow rate capacity than bladder pumps). Extracted groundwater and NAPL would be conveyed to a treatment system. Extracted fluids would be separated by primary, secondary, and tertiary treatment unit processes such as coalescing plate separators followed by walnut shell filters followed by granular activated carbon (GAC). Walnut shell filters and GAC were assumed over granular organoclay adsorbers based on lower estimated life cycle costs. The primary treatment would be performed adjacent to a treatment building housing the filters, tertiary treatment system, back wash tank, creosote storage tank, electronics, and controls.

The unit cell dimensions for cold water flooding are 100 feet by 75 feet by 26 feet thick in the FWDA and 125 feet by 80 feet by 16 feet thick in the TFA. This is equivalent to 0.17 and 0.23 acres, respectively. Figure 8 illustrates the conceptual well field in plan view. Eight extraction wells, two injection wells, and two to three monitoring wells are planned for each cold water flooding unit cell. Preliminary screen intervals are also shown on Table 2.

Design parameters included design hydraulic gradient, extraction well flow rate, injection well flow rate, and well spacing. The design hydraulic gradient was established by considering the hydraulic conductivity of each focus area, neutral oil/water wetness of site soils and the NAPL viscosity. Extraction well flow rates were calculated, see Appendix A, from estimates of hydraulic conductivity neglecting constant head boundaries and relative permeability behavior. Injection flow rates were established by extraction well counts and estimated flow rates. Hydraulic control is a key design parameter given the proximity of the site to the Willamette River and the need to maintain hydraulic control and under varying river stages. If hydraulic control is not maintained, the flooding technology could result in a net increased discharge to the river, resulting in impacts to endangered salmonids and other ecological receptors.

5.4 Innovative Technology 2: Hot Water Flooding

Hot water flooding is a similar physical process to cold water flooding, except that treated groundwater is heated with a natural gas-fired boiler and reinjected. Heating the groundwater prior to injection will result in higher subsurface temperatures, which reduces the viscosity of NAPL. The reduction in viscosity of the NAPL and increase in hydraulic gradients mobilizes NAPL towards recovery wells. Both the water and NAPL density will be reduced, resulting in only a slight decrease of NAPL specific gravity, about 1% as shown on Table 4-6 of the Updated CSM (Appendix B). Although the change in specific gravity is negligible, some of the DNAPL may become LNAPL, possibly providing some benefit for capture, although neutral buoyancy is expected.

Hot water flooding is expected to operate for 36 months but may be completed in 12 to 48 months. Hot water flooding would begin with several months of cold water flooding to capture the initially mobile fraction of NAPL and manage the influx of NAPL while the treatment system is optimized and hydraulic response to injection is measured. Once heating begins three to nine months will be required to achieve target temperatures. Hot water flooding would continue until NAPL recovery declines and temperatures in the target zone indicate that the treatment goals have been achieved. The heat would then be discontinued and cold water flooding would continue while the formation cools.

Hot water flooding would require 4 to 6-inch pressure injection wells and 4-inch extraction wells with submersible pumps. Bladder pumps would be preferred to minimize shearing of the extracted fluids however adequate flow rates may not be achieved. Extracted groundwater and NAPL would be conveyed thru insulated piping to a treatment system. Extracted fluids would be treated by primary, secondary, and tertiary treatment unit processes such as coalescing plate separators followed by walnut shell filters followed by advanced oxidation (AOP). Robust tertiary treatment using AOP is likely needed because hot water flooding will result in increased solubility of dissolved creosote constituents. Other treatment alternatives such as GAC, granular organoclay or membrane filtrations could be used but were not considered given the scope of the ITE. GAC and granular organoclay would likely be cost prohibitive due to the high load of NAPL and dissolved constituents. Membrane filtration has not performed well at the McCormick and Baxter site historically. Therefore AOP using ozone and peroxide was assumed because of the flexibility in operational parameters, cost, and performance.

The unit cell dimensions for hot water flooding are the same as cold water flooding. Figure 8 illustrates the conceptual well field in plane view. Eight extraction wells, two injections wells, and two monitoring wells are planned per hot water flooding unit cell. Preliminary screen intervals are shown on Table 2.

Design parameters included target temperature for injected treated groundwater, design hydraulic gradient, extraction well flow rate, injection well flow rate, and well spacing. The target temperature for injected treated groundwater was established based on reducing viscosity of NAPL by greater than 90% and evaluation of thermal rating for various pipe materials. Site-specific measurements of NAPL viscosity versus temperature are included in Table 4-6 of the draft Updated CSM (Appendix B). The design hydraulic gradient was established by considering hydraulic conductivity of each focus area, the neutral oil/water wetness of site soils and the NAPL viscosity versus temperature. Extraction well flow rates were calculated, see Appendix A, from estimates of hydraulic conductivity neglecting constant head boundaries and relative permeability behavior. Flooding technologies would require extensive hydraulic analysis and testing prior to field deployment to further evaluate the competing effects of the fluctuating head imposed by the Willamette River, no flow boundary imposed by the sheet pile wall, vertical flow from below, and superposition effects of nearby wells that could not be considered within the scope of the ITE. Injection flow rates were established by extraction well counts and estimated flow rates.

5.5 Innovative Technology 3: In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) involves the injection of a chemical oxidant to achieve in-place destruction of organic chemicals or mixtures such as creosote. The four most common oxidants are: permanganate, hydrogen peroxide, ozone, and persulfate. All four chemical oxidants will destroy polycyclic aromatic hydrocarbons (PAHs) and chlorinated phenols. However, creosote is a complex mixture of hundreds of organic constituents with varying reactivity with oxidants, thus permanganate, the oxidant with the lowest oxidation potential, was eliminated from additional consideration. Hydrogen peroxide and persulfate were also eliminated from additional consideration because they are liquid oxidants that are generally delivered in batches to the target zone and the volume of oxidant that would be required is not logistically feasible.

A continuous supply of oxidant to the subsurface was deemed necessary to treat NAPL. ISCO is more commonly used to treat dissolved constituents as compared to NAPL, therefore a larger and continuous supply of oxidant was deemed necessary. Ozone is generated on-site at the time of use and can be continuously delivered to the target zone by automated equipment. Continuous on-site generation of ozone substantially increases the mass of oxidant available to destroy NAPL over time. The mass of NAPL in the subsurface is subject to uncertainty therefore stoichiometric calculations of ozone requirement were not possible at this time. Additionally, stoichiometric calculations have limited value for ozone-based ISCO design due to the combination of physical, biological, and chemical processes that occur during ozone-based ISCO. Bench and field pilot tests are necessary to determine the actual ozone requirements. Therefore, the ozone deployment scenario was based on a prior application of ozone at a creosote site (Marvin et al, 1998) and expected air sparge flow rates for injection wells (Clayton, 1998). ISCO using ozone may require 12 to 36 months to remove NAPL however it is expected that NAPL removal could be achieved in 24 months of ozone operations.

Ozone-based ISCO will require gas injection wells and soil vapor extraction (SVE) wells. For each unit cell, on the order of fifty pounds per day of ozone would be generated on-site and distributed to the injection wells. The distribution system will pulse the ozone to various combinations of injection wells. The SVE system will run continuously to prevent any fugitive emissions and enhance control of the injected ozone. Off-gas from the SVE system will be treated with a catalytic ozone destruction unit and vapor phase GAC.

Additional information concerning ISCO and ozone may be found in the United States Environmental Protection Agency's *A Citizen's Guide to Chemical Oxidation* (EPA 542-F-01-013) that is available at http://www.clu-in.org/products/citguide/. The Interstate Regulatory Technology Cooperation organization also has Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater, 2nd Edition (January 2005) available at http://www.itrcweb.org/gd_ISCO.asp.

The unit cell dimensions for ISCO are 120 feet by 120 feet by 26 feet and 16 feet thick for the FWDA and TFA, respectively. Figure 8 illustrates the conceptual well field in plane view. Ten ozone injection wells, seven SVE wells, and two monitoring wells are planned per ozone unit cell. Preliminary screen intervals are shown on Table 2.

Design parameters included ozone injection concentration, ozone production rate, and flow rates for injection and extraction wells. The ozone demand will be high due to the large mass of organics within the NAPL. Injection concentrations were estimated to range from 0.3 to 3 percent ozone by weight. The daily ozone production rate was estimated at 50 pounds per day. This size ozone generator achieved 90 percent removal of creosote from a site located in Windsor, California in 12 months (Shaw Corporation, 2003). Larger ozone generators become cost prohibitive while smaller ozone generators will not provide adequate ozone to destroy NAPL. The properties of the soils at the site suggest that gas injection rates on the order of ten standard cubic feet per minute can be achieved, although it may be prudent to operate an ozone system at lower flow rates during pilot testing or initial operations. An air boost system will likely be required to achieve the design injection flow rate and contact NAPL at distance from the injection wells. The SVE flow rates were estimated at 125% of the total ozone flow rate per SVE well.

5.6 INNOVATIVE TECHNOLOGY 4: ELECTRICAL RESISTIVE HEATING

Electrical resistive heating (ERH) most commonly involves six-phase power applied to seven electrodes in a hexagonal pattern. Sheet pile walls have also been used as electrodes. The electricity resistively heats the soil and vaporizes soil moisture creating steam. NAPL mobility is increased due to reduction in NAPL viscosity, the more volatile fraction of creosote will vaporize, and increased pressure gradients are generated due to steam formation. The maximum target temperature for ERH is 212 degrees F because some soil moisture is necessary to maintain conductivity of the soil therefore volatilization accounts for less mass removal as compared to viscosity reduction and pressure gradients from steam. Vapor phase removal becomes a more dominate removal mechanism as NAPL saturations decrease with time.

ERH is the fastest of the innovative treatment technologies that were retained. NAPL removal may be achieved in as little as 5 months and up to 12 months. The expected ERH treatment time frame is 9 months.

The electrodes are constructed as a combination of electrodes and total fluids recovery wells. Soil vapor, steam, groundwater, and NAPL will be recovered and conveyed to a treatment system. A condenser is initially used to separate NAPL, water, and vapors. NAPL is collected and disposed. The NAPL-water stream is treated with unit processes similar to hot water flooding. These treatment processes are likely coalescing plate separators followed by walnut shell filters followed by advanced oxidation (AOP). Vapors would be treated with vapor-phase GAC.

Additional information concerning ERH and other thermal technologies may be found in the United States Environmental Protection Agency's A Citizen's Guide to *In Situ* Thermal Treatment Methods (EPA 542-F-01-012) is available at http://www.clu-in.org/products/citguide/. The Department of the Navy Environmental Program also provides and excellent overview of thermal remediation techniques that may be found at http://enviro.nfesc.navy.mil/erb/erb_a/support/rits/presentations/2000-10-napl.pdf.

The unit cell dimensions for ERH are 56 feet by 112 feet by 26 feet thick. This is equivalent to 0.14 acres. Figure 8 illustrates the conceptual well field in plane view. Twelve electrodes and total fluids extraction wells, two monitoring wells, and eight thermocouples are planned per ERH unit cell. Preliminary screen intervals are shown on Table 2.

Design parameters included electrode power, design hydraulic gradient, target temperature, maintenance energy factor and extraction well flow rate. The electrode power requirement and maintenance energy factor were based on technology vendor input. The design hydraulic gradient required to maintain hydraulic control was the same as that used for cold and hot water flooding. The target temperature is the maximum operational temperature for ERH. The maximum temperature is 212 degree F in order to maintain electrical conductivity of the soil. The boiling temperature for creosote is generally greater than 600 degrees F however a fraction of the creosote will volatilize at 212 degree F and heating tends to increase this fraction as a result of partial pressure reductions. The vapor extraction well flow rate was assumed at 80 SCFM per electrode/recovery well location.

6.0 DETAILED FEASIBILITY EVALUATION

The detailed feasibility evaluation was performed as described in Section 1.2.2. This section provides a detailed evaluation of each of the technologies with respect to the evaluation criteria (effectiveness, long-term reliability, implementability, implementation risk, and cost. Tables 2 to 5 provide the details of the feasibility evaluation and supporting calculations are included in Appendix A.

6.1 CURRENT CONDITION, DISCONTINUE EXTRACTION

Under this approach, no additional NAPL would be extracted. Remaining mobile NAPL outside of the barrier wall would continue to migrate until it either reaches residual saturations, migrates into the sediment cap where the granular organoclay will sorb the NAPL, or in the event the granular organoclay proves not to have the capacity to sorb the remaining mobile NAPL, reaches the river. An assumption with this alternative is that if NAPL were to breach the granular organoclay or flow through areas not capped with granular organoclay, then the sediment cap would be repaired to prevent adverse effects to the river.

6.1.1 Effectiveness

This approach would not further remove or destroy NAPL in either of the focus areas. However, it does have the added safeguard of sediment cap repair should NAPL break-through occur.

6.1.2 Long-term Reliability

This approach may reduce the long-term reliability of the current remedy.

6.1.3 Implementability

This approach is readily implemented.

6.1.4 Implementation Risk

There is also no implementation risk.

6.1.5 Cost

Maintaining the current condition (without extraction) does not involve any additional cost for NAPL recovery, although costs for cap repair were estimated. Cap repair would be implemented if NAPL breaks through the sediment cap. Tables B-1 and B-2 in Appendix B provides the details of the cost estimates for a granular organoclay layer and an organoclay blanket repair, respectively. Two potential repair scenarios were chosen to attempt to span the range of potential costs. The organoclay blankets are less expensive, thus a small patch area (225 sq. ft.) for using the blanket was chosen as the low cost end. For the high cost end, a large area (1000 sq. ft.) using granular organoclay which is more expensive to place was selected to obtain a representative range of cap repair costs using organoclay. The costs are based on actual organoclay placement costs at the site in 2004 and 2005.

6.1.6 Technology Endpoint

There is no technology endpoint for this approach.

6.2 CURRENT CONDITION AND SINGLE PHASE EXTRACTION

NAPL is currently extracted weekly from six wells outside of the barrier wall when NAPL accumulates to thicknesses of greater than 0.4 feet in a well. The NAPL recharges in the wells soon thereafter. DEQ has optimized manual recovery procedures and currently recovers on the order of 80 gallons a month site-wide, and approximately 30 gallons a month outside the barrier wall. However, the well network is not optimized for NAPL recovery in each of the focus areas.

6.2.1 Effectiveness

This technology is not highly effective because NAPL recovery is restricted to a small area surrounding the well. NAPL saturations adjacent to the extractions wells must remain above residual saturations to maintain NAPL connection to the recovery well and allow NAPL to flow into the well. A large area of LNAPL and DNAPL occurrence in the FWDA under the high pressure sewer main and BNSF railroad trestle would remain unavailable for NAPL recovery.

6.2.2 Long-term Reliability

Single-phase extraction has a low long-term reliability as potentially mobile NAPL will remain above residual saturations at short distances from the recovery wells. This technology can locally reduce small areas with high saturations of mobile NAPL to residual saturations over time but may leave NAPL above residual saturations behind outside of the area of influence of the extraction well. There is low long-term reliability that single-phase extraction would extract sufficient NAPL to reduce uncertainties related to the remedy such as whether the organoclay is located to intercept all NAPL that would otherwise discharge to the river and whether there is adequate organoclay to sequester the NAPL indefinitiely.

6.2.3 Implementability

This technology is highly implementable. Currently, it involves recovering LNAPL from wells using a bailer and recovery of DNAPL from wells using an air-driven positive displacement pump. The NAPL is pumped or bailed into five gallon buckets at the well and transported to 55-gallon drums at a staging location.

6.2.4 Implementation Risk

There is little implementation risk. There is no threat of mobilizing additional NAPL to the river as the physical characteristics of the NAPL are not altered and the only gradient changes are in the direct vicinity of each extraction well with the increase in gradient towards the well. There a small implementation risk of above-ground spills during NAPL recovery contaminating the soil cap. Careful field protocol can reduce the risk of above ground spillage.

6.2.5 Cost

The cost for removing the NAPL from outside the barrier wall is approximately $5,000/month or about $100/gallon. Tables B-3 and B-4 in Appendix B provide the cost details for single-phase NAPL recovery in the TFA and FWDA. Costs for single phase recovery in the TFA and FWDA are based on known costs at the site for similar activities. Costs are similar for each area, except the cost summary for the TFA assumes 3 additional recovery wells will be installed in the TFA area to provide a greater area of coverage for NAPL recovery.

6.2.6 Technology Endpoint

The technology endpoint for manual recovery would be based on an observed decline in NAPL mass recovery over time. This already had occurred at most extractions wells across the site although after construction of the barrier wall, recovery increased. This is likely due to a combination of causes including changes in gradients due to installation of the wall, ground vibration during construction mobilizing NAPL, and continued optimization of manual recovery procedures.

6.3 Innovative Technology 1: Cold Water Flooding

Cold water flooding is used to "push and pull" NAPL toward a recovery and collection system. The simultaneous injection and extraction of groundwater increases hydraulic gradients to mobilize NAPL faster and at lower saturations than flow under natural conditions.

6.3.1 Effectiveness

Cold water flooding can recover NAPL to close to the residual saturation. The residual saturation is the amount of NAPL that remains trapped as ganglia and/or pendular rings in soil pores by capillary forces. Measured residual saturations for the McCormick and Baxter site ranged from 7 to 12 percent (CSM Section 4.2.5.5 citation).

The NAPL recovery efficiencies for cold water flooding, shown on Table 2, were calculated by estimating the range of initial saturations from the CSM NAPL mobility calculations and assuming that cold water flooding reduces the NAPL saturation to the average of the measurements of residual NAPL saturation from the CSM report. The NAPL recovery efficiencies for cold water flooding ranged from 22 to 65 percent with an expected value of 39 percent.

It is assumed that residual NAPL will remain after cold water flooding at comparable levels to the residual saturation that would remain under the current condition; however, cold water flooding will accelerate the rate of NAPL movement towards a recovery system as a result of hydraulic gradients toward the recovery system.

6.3.2 Long-term Reliability

The long-term reliability of cold water flooding is moderate to high dependent on the operational duration and heterogeneity of the subsurface. In some areas where NAPL saturations are high or geologic conditions are less favorable cold water flooding may bypass some NAPL. Bypassing can be overcome by operating the cold water flood for a longer period of time and/or targeting well screens. The neutral wettability of the media suggests that stratigraphic contacts may not result in accumulations of NAPL that would reduce the hydraulic conductivity of the contact; however, variations in hydraulic conductivity due to soil texture may cause flow bypassing during a cold water flood.

Reliable operations of a cold water flood system are dependent on minimizing emulsification of the NAPL-groundwater mixture, a robust above ground treatment system, and proper well construction. Bladder pumps have been selected for the extraction wells to minimize emulsification and maximize flow rates. Suction lift pumping using low shear pumps is not feasible given the topography of the site and seasonal flooding events. The above ground treatment system is assumed to consist of gravity settling in coalescing plate separators followed by granular filtration using walnut shell media followed by granular activated carbon (GAC).

Overall, cold water flooding will have a moderate to high degree of long-term reliability with respect to reduction in mobility of NAPL.

6.3.3 Implementability

Cold water flooding can be implemented at the site. Additional hydraulic design would be required to evaluate the effects of the Willamette River as a fluctuating hydraulic boundary and the sheet pile wall as a no flow boundary with respect to well configurations and flow rates. These factors may tend to balance one another but may require adjustments to the well field configuration or individual extraction well flow rates. The detailed hydraulic design of a cold water flood may also find that it is necessary to direct a fraction of the treated groundwater to the storm water detention pond for the cap.

Adequate high voltage power (460VAC/3P/100A) is available at the former groundwater treatment building. Prior experience with above ground separation of NAPL and groundwater at the site was problematic and costly.

6.3.4 Implementation Risk

The implementation risk of cold water flooding is moderate to low based on expected hydraulic control of the system. The most significant implementation risk would occur if a small number of the extraction wells were not operated or did not perform as designed. The controls system would be designed to account for this problem thereby managing the threat.

6.3.5 Cost

The capital cost of cold water flooding is controlled by the treatment system unit processes and the building necessary to house the equipment and controls. The highest cost unit treatment process is granular filtration with walnut shell media followed by granular activated carbon (GAC) vessels and initial charge of GAC. The mechanical installation costs are the next most expensive line, followed by the treatment building. Electrical installation and controls costs exceed well pumps, air supply for the well pumps, transfer pumps and coalescing plate separator costs. Wells costs were based on wire-wrapped well screens to maximize the open area with gravel filter packs. Injection wells are assumed to be 6-inch diameter with an API Class G grout while extraction wells are assumed to be 4-inch in diameter.

The operating costs for cold water flooding are largely dependent on the duration of the treatment and GAC usage rate. The duration of operations controls the electricity costs and cold water flooding is expected to require the longest treatment duration of the retained innovative technologies per unit cell. The operating costs are sensitive to the GAC usage rate and creosote recovery rate which are difficult to project in the absence of bench testing and field pilot test results, respectively.

6.3.6 Technology Endpoint

The technology endpoint for cold water flooding would be based on a decline in NAPL recovery. When the NAPL recovery rate begins declining relative to cumulative system flow rate, one can predict the technology end point. The extraction end point for water flooding would be a percentage of the initial NAPL recovery rate (e.g., 90%) and compared to the estimated volume of mobile NAPL in the treatment zone. This technology endpoint would be determined based on a cost-benefit analysis.

6.4 Innovative Technology 2: Hot Water Flooding

Hot water flooding would be similar to cold water flooding with the addition of a natural gas-fired boiler to heat the treated groundwater prior to injection. Heating the groundwater prior to injection will cause the subsurface to be heated which will reduce the viscosity and specific gravity of NAPL. Reduction in viscosity of the NAPL and increases in the hydraulic gradients are expected to be the primary mechanisms for mobilization of NAPL towards the recovery system.

6.4.1 Effectiveness

Hot water flooding can recover NAPL to less than the residual saturation and will likely reduce the residual saturation value by up to 50 percent. The residual saturation is the amount of NAPL that remains trapped as ganglia and/or pendular rings in soil pores by capillary forces. Capillary forces are dependent on temperature and tend to decrease with increasing temperature. The measurements of NAPL viscosity versus temperature were extrapolated to evaluate the target temperature for hot water flooding as summarized in Appendix A. The measured residual saturations of NAPL at the McCormick and Baxter site ranged from 7 to 12 percent (CSM Section 4.2.5.5 citation).

The NAPL recovery efficiencies for hot water flooding, shown on Table 3, were calculated by estimating the range of initial saturations from the CSM NAPL mobility calculations and assuming that hot water flooding would reduce the range of initial NAPL saturations to the 50 percent of the average of the measurements of residual NAPL saturation (CSM citation 4.2.5.5). The NAPL recovery efficiencies for hot water flooding ranged from 43 to 82 percent with an expected value of 53 percent.

Less residual NAPL will remain after hot water flooding as compared to cold water flooding; however, both technologies reduce the NAPL saturations to immobile levels at ambient groundwater conditions. Hot water flooding is expected to accelerate the rate of NAPL movement towards a recovery system as a result of lower NAPL viscosity as a result of heating.

6.4.2 Long-term Reliability

The long-term reliability of hot water flooding is moderate to high depending on the operational duration and heterogeneity of the subsurface. In some areas where NAPL saturations are high or geologic conditions are less favorable hot water flooding may bypass some NAPL. The effect of bypassing are lower for hot water flooding than cold water flooding due to increased hydraulic conductivity of NAPL due to viscosity reductions.

Reliable operations of a hot water flood system are dependent on minimizing emulsification of the NAPL-groundwater mixture, a robust above ground treatment system, and proper well construction. Bladder pumps have been selected for the extraction wells to minimize emulsification while maximizing flow rate. Suction lift pumping using low shear pumps is not feasible given the topography of the site and potential for seasonal flooding events. The above ground treatment system is assumed to consist of gravity settling in coalescing plate separators followed by granular filtration using walnut shell media followed by advanced oxidation processes (ozone and peroxide). GAC and granular organoclay were deemed inappropriate for hot water flooding because heating increases the recovery of NAPL and solubility of NAPL components causing the GAC and granular organoclay utilization rates to increase substantially. An AOP is more flexible with respect to variable operating conditions.

Overall, hot water flooding will have a moderately high degree of long-term reliability with respect to reduction in mobility of NAPL due to its ability to reduce the residual saturation of NAPL such that when the site cools, the residual NAPL saturations will be below levels that allow NAPL migration.

6.4.3 Implementability

Hot water flooding can be implemented at the site. Additional hydraulic design would be required to evaluate the effects of the Willamette River as a fluctuating hydraulic boundary and the sheet pile wall as a no flow boundary. These factors may balance one another but could require adjustment of the well field configuration and/or extraction well flow rates. The thermal design of a hot water flood may also find that it is more cost effective to direct a fraction of the effluent to an alternate discharge location, such as the storm water detention pond for the cap, to reduce fuel costs and maintain hydraulic control across the treatment zone.

Adequate high voltage power (460VAC/3P/100A) is available at the former groundwater treatment building. A high pressure gas main is available to fire the hot water boiler parallel to the Burlington Northern railroad tracks.

6.4.4 Implementation Risk

The implementation risk of hot water flooding is moderate based on expected hydraulic control of the system. The most significant implementation risk would occur if a number of the extraction wells were not operated or did not perform as designed. The controls system would be designed to account for this problem thereby managing the threat. The extraction well pumps and the conveyance system may require upgraded materials of construction due to increased operating temperatures. Hot water flooding will carry increased implementation risk compared to cold water flooding because heated groundwater may serve to mobilize increased discharges of dissolved phase NAPL constituents.

6.4.5 Cost

The capital cost of hot water flooding is dominated by the treatment system unit processes. The highest cost unit treatment process is AOP followed by granular filtration with walnut shell media. The mechanical installation costs are the next most expensive line item followed by the treatment building and then boiler. Electrical installation and controls costs exceed well pumps, air supply for the well pumps, transfer pumps and coalescing plate separator costs. Wells costs were based on wire-wrapped well screens to maximize the open area with gravel filter packs. Injection wells are assumed to be 6-inch in diameter with an API Class G grout while extraction wells are assumed to be 4-inch in diameter.

The operating costs for hot water flooding are largely dependent on the duration of the treatment and associated utility costs. The duration of operations controls the electricity costs and natural gas costs. The operational duration for hot water flooding is expected to be less than cold water flooding; however, natural gas costs are expected to cause the overall operating costs to be higher for hot water flooding.

6.4.6 Technology Endpoint

The technology endpoint for hot water flooding would be based on the decline in NAPL recovery curve similar to the end point for the cold water flooding technology. In general, hot water flooding is expected to recover 100 percent of the mobile NAPL fraction and reduce the residual saturation of NAPL by 50 percent.

6.5 INNOVATIVE TECHNOLOGY 3: IN SITU CHEMICAL OXIDATION

In situ chemical oxidation involves the injection of a chemical oxidant to achieve in place destruction of organic chemicals or mixtures such as creosote. Ozone gas will be generated at low percent concentrations from air and injected as gas.

6.5.1 Effectiveness

In situ chemical oxidation using ozone gas can destroy creosote NAPL and dissolved creosote components. In situ chemical oxidation using ozone will destroy or collect creosote components as a result of three processes: chemical oxidation, volatilization, and aerobic biological activity.

The ozone would be pulsed into injection wells in groups to maximize the biodegradation component while minimizing displacement of NAPL as a result of gas injection. Direct chemical oxidation of the NAPL mass to carbon dioxide (CO_2) will be limited by the amount of ozone and stoichiometric factors. Ozone oxidation normally proceeds to low molecular weight aldehydes and ketones that have improved biodegradability as compared to parent compounds (Langlais, et al, 1989; Legube, et al, 1981; Stephenson et al, 1979). Ozone degrades into oxygen which will increase dissolved oxygen levels encouraging aerobic biodegradation of the aldehydes and ketones in addition to other organic compounds.

The NAPL recovery efficiency estimates range from 50 percent to 99.9 percent with an expected value of 90 percent as shown on Table 4. The expected value was taken from experience at the Ecodyne Pond site in Windsor, California (Marvin, 1998). Ozone injection at this creosote site eliminated NAPL from lysimeters and reduced soil concentrations by at least 90 percent (Marvin, 1998).

6.5.2 Long-term Reliability

The long-term reliability of ISCO using ozone gas is moderate to high dependent on the size of the ozone generation system and heterogeneity of the subsurface.

If a larger ozone generation facility is used, more NAPL can be destroyed per day and reliability would be improved. Improved ozone production may be achieved by generating ozone from oxygen rather than air; however, the capital costs will increase as a result of a larger air compressor and dryer system and additional engineering design and process monitoring is needed to ensure safe operations in an elevated oxygen environment.

The heterogeneity of the subsurface may affect the gas flow behavior of the ozone-air mixture. No air sparge pilot test data is available to assess the injection well flow rates and pressures; as well as the uniformity of gas distribution in the subsurface.

Overall, ISCO using ozone gas will have a moderate to high degree of long-term reliability with respect to reduction in mobility of NAPL due to the destructive nature of the technology.

6.5.3 Implementability

Ozone-based ISCO can be implemented at the site. Additional pilot testing to asses the ozone requirement and gas sparging physics would allow a more detailed design of the ozone system. Adequate high voltage power (460VAC/3P/100A) is available at the former groundwater treatment building.

6.5.4 Implementation Risk

Gaseous injection may cause displacement and/or volatilization of NAPL. Gas injection is used in the petroleum industry to enhance oil recovery by displacing NAPL towards oil wells. However, gas enhanced oil recovery is based on continuous injection of much larger volumes of gas than pulsed injection of ozone of ISCO. Operations of an ozone-based ISCO process would begin with low flow rate injection along the river to isolate NAPL from the river. Additional design analysis would be required to prevent NAPL displacement and evaluate the need for NAPL-groundwater recovery, treatment, and discharge with an ozone-based ISCO system.

Fugitive emissions of creosote or ozone would be controlled by the SVE system and catalytic off-gas treatment process. The ozone reducing catalyst bed also catalytically destroys organics although high organics loading can deactivate the catalyst over time. If hydrogen peroxide is added to the ozone system to improve the NAPL destruction rate, a larger more robust SVE system will be required due to the decomposition of hydrogen peroxide in 30 to 50 times the injected volume as oxygen gas. Additional evaluation of the potential to form bromate, haloacetic acids (HAA), and total trihalomethanes (TTHM) may be required.

Chemical oxidation will result in partial oxidation of the high molecular weight PAHs contained in the NAPL creosote mass, generating a more biodegradable breakdown product. An increase in the loading of these lower molecular weight breakdown products may manifest themselves in somewhat contradictory changes to toxic effects realized by aquatic receptors, as follows:

- The breakdown products (low molecular weight PAHs) are less bio-accumulative, and will result in lower overall toxicity from a trophic transfer perspective;
- In aquatic systems, PAHs tend towards decreased toxicity with decreased molecular weight (Eisler 1987b), however this is endpoint specific;
- Narcosis effects from PAH exposure are realized on a molar level, thus with increased bioavailability of lower molecular weight hydrocarbons, increased toxic effects could be realized; and
- Increased toxicity from PAHs has been observed due to UV-photoactivation in aquatic systems.

It is important to note that in order for any of these toxicity effects (positive or negative) to be realized in the river the organoclay must fail. If further consideration is given for implementation of this innovative technology, the design stage should incorporate some additional analysis with regard to increased cap life effects from increased dissolved phase loading, balanced with a rigorous analysis of both the abiotic and biotic degradation rates that will occur in the subsurface, before the breakdown products reach the organoclay sediment cap and the river.

A common concern with respect to underground utilities is that ozone will react with many metals and cause corrosion. Typical ozone reaction rates in the subsurface tend to limit the maximum distance of ozone transport to less than 40 feet (Clayton, 1998) however special controls may be required to protect underground utilities. Figure 8 illustrates that SVE wells would be located about the perimeter of the treatment area to prevent the migration of ozone outside of the ISCO unit cell.

Ozone is a toxic gas and requires trained operators and staff working in the treatment area. Single phase extraction and monitoring well gauging procedures would require modification to mitigate hazards to site workers.

6.5.5 Cost

The capital costs for ozone-based ISCO are controlled by the ozone generation system. The ozone generation system consists of an air compressor, refrigerant dryer, air receiver, ozone generator, and air conditioning system. Ozone generation systems are typically enclosed in trailers or cargo containers instead of a permanent building. Controls and distribution system piping are the next highest capital costs factors. The controls system continuously monitors the ambient air, equipment operating conditions, and runs the injection wells timers and sequencing. Distribution piping is constructed from Teflon and 316 stainless steel due to the aggressive nature of ozone. The

SVE system is relatively low cost due to the low flow rate required to prevent fugitive emissions. A higher flow rate than necessary can waste ozone and increase overall costs.

The operating costs for ozone-based ISCO are largely dependent on the duration of the treatment. The duration of operations controls the electricity costs that are the single largest operating cost factor.

6.5.6 Technology Endpoint

The technology endpoint for ozone-based ISCO would be based on declines in NAPL observed in monitoring wells and soil sample results. The NAPL in monitoring wells would be periodically removed by manual pumping and recovery of NAPL mass accumulations would be evaluated to assess removal of mobile NAPL by ISCO. Soil samples would also be collected before, during, and after ISCO operations to measure NAPL saturations at locations between monitoring wells.

6.6 INNOVATIVE TECHNOLOGY 4: ELECTRICAL RESISTIVE HEATING

Electrical resistive heating (ERH) most commonly involves six-phase power applied to six of seven electrodes in a hexagonal pattern (the minimum unit cell contains two linked hexagonal arrays). The electricity resistively heats saturated soil and vaporizes soil moisture creating steam. The steam pushes NAPL towards recovery wells while heating increases the volatility of creosote constituents and reduces the NAPL viscosity and density. Total fluids are extracted at each electrode location collecting steam, soil gas, groundwater, and NAPL.

6.6.1 Effectiveness

ERH can recover NAPL and result in very low concentrations of creosote constituents in soil. The steam generated by ERH is very effective in pushing NAPL towards recovery wells and can be varied to create pressure cycles that can mobilize NAPL at very low saturations. The steam generation is rather uniform across the treatment zone further stripping creosote constituents from saturated soils and groundwater.

ERH at a creosote site will rely on steam displacement, distillation and stripping. Biological activity within the ERH treatment zone also increases with increasing temperature and will continue as the target zone cools down providing residual groundwater treatment after the active phase of ERH is complete (Udell et al, 1996; Environmental Protection Agency, 2004; Beyke, G. and T. Powell, 2005; Huesemann, et al, 2002).

The NAPL recovery efficiency estimates range from 99 percent to 99.99 percent with an expected value of 99.9 percent as shown on Table 5. The expected value was selected based on input from Thermal Remediation Services, Inc. that is operating the Fort Lewis, Washington ERH treatability study.

6.6.2 Long-term Reliability

The long-term reliability of ERH is high due to the expected removal efficiency of NAPL and the relatively low sensitivity of ERH to subsurface heterogeneity.

Reliable operations of an ERH system are dependent the experience of the technology contractor with issues such as high temperature operations of the total fluids recovery system and the electrical service. A robust above ground treatment system and proper well construction ensure reliable operations and a short duration of treatment. The above ground treatment system is assumed to consist of a condenser, gravity settling in coalescing plate separators followed by granular filtration using walnut shell media followed by AOP using ozone and hydrogen peroxide. Off-gas will be collected and treated using GAC or a catalytic oxidizer. A catalytic oxidizer allows for variable influent concentrations. Additional design of the catalytic oxidizer may be necessary in the FWDA due to the chlorophenol concentrations in the NAPL that are not observed in the TFA.

Due the aggressive nature of this innovative treatment technology, ERH will have a high degree of long-term reliability with respect to reduction in mobility of NAPL.

6.6.3 Implementability

ERH can be implemented at the site. Inflow of cold water from the river may result in additional power costs for ERH as compared to applications at other sites. This factor will require additional design consideration and a pilot study to ensure the target temperature of 212 degrees F can be achieved and maintained for an adequate period of time.

Additional evaluation of the NAPL boiling points will also be required prior to completing a 30 percent design. This information would be used to evaluate the off-gas mass loading to the catalytic oxidizer and may suggest that GAC is a more cost effective alternative for off-gas treatment. Disposal of the treated groundwater may prove problematic during the design process although lower flow rates and a less robust treatment system may prove adequate and reduce costs.

6.6.4 Implementation Risk

The implementation risk of ERH is moderate based on the expected hydraulic control of the extraction system and ability to adjust the applied power. The most significant implementation risk would occur if a number of the extraction wells were not operated or did not perform as designed. The controls system would be designed to monitor the temperature inside and adjacent to the treatment zone to ensure that the vapor is collected by the recovery system and does not displace NAPL into the river or exit from the ground surface.

Waterways Experiment Station (now ERDC) performed bench tests in 1998, to evaluate potential effects of steam on a soil-bentonite (SB) slurry wall at Wyckoff Superfund Site. The tests were done by filling columns with sand and a 4 to 5-inch thickness of SB material, and then injecting steam through the column. Site NAPL was added to some of the columns. The SB slurry wall material consisted of clayey sand soil from Port Ludlow WA (borrow area near Wyckoff) mixed with 5-10% of a commercial clay amendment. The clay amendments tested were attapulgite and three treated bentonite products designed for use in saline or brine environments. The report concluded:

- Overall, the slurry wall material was not adversely affected by steam injection.
- Steam injection increased the flow of water through the slurry wall material, primarily because of the increased pressure differential across the wall.
- Steam injection did not cause NAPL to penetrate the wall.
- Pressure has more of an adverse effect on the wall material than elevated temperatures.
- Pressure effects can be controlled by placing vents (or extraction wells) along the wall.

During ERH the voltage measured at the ground surface is generally less than 15 volts (Cummings, 2000) and does not present a safety hazard; however, site access would be limited given the high voltage of the distribution system. Site operational procedures will require modification to address the hazard of near boiling point water.

6.6.5 Cost

The capital cost of ERH is controlled by the treatment system unit processes and mechanical installation. The highest cost unit treatment process is granular filtration with walnut shell media followed by the AOP system. The mechanical installation costs and treatment system building are the next most expensive capital costs followed by electrical installation and equipment. Additional capital costs and project duration may be incurred due to the need to upgrade the power service onto the site. The SVE collection system, catalytic oxidizer, extraction well pumps, and air supply are also significant capitals costs. Wells costs were based on metallic wells with wire-wrapped well screens and an API Class G grout to tolerate the heat.

The operating costs for ERH are largely dependent on the duration of the treatment and subsequent power consumption. The duration of operations is short for ERH, often as little as 5 months for volatile compounds such as chlorinated ethenes, and therefore power costs are comparable to the flooding technologies. The operating costs are also may be sensitive the creosote recovery rate which is difficult to project in the absence field pilot test results.

The costs of ERH may be higher than the other innovative technologies due to the smaller size of the unit cell. This may be addressed by operating a smaller number of units cells at a time over a longer duration thereby further minimizing the capital costs however further analysis of these options is beyond to scope of the ITE.

6.6.6 Technology Endpoint

The technology endpoint for ERH would be based on maintaining the target temperature for an adequate period of time. This endpoint would be detected by a decrease in the NAPL mass recovery rate from the total fluids recovery system. The removal of NAPL would be compared to an initial estimate of the NAPL mass based on the data collected during electrode installation. In general, ERH is expected to be the most effective of the innovative technologies evaluated with respect to NAPL recovery and would likely eliminate the mobile NAPL from the treatment zone.

6.7 COMPARATIVE EVALUATION OF TECHNOLOGIES

The comparative evaluation of the innovative technologies to one another is presented in Table 6. Each of the innovative technologies was compared to each other technology with respect to the five primary evaluation criteria:

- Effectiveness;
- Long-term Reliability;
- Implementability;
- Implementation Risk; and
- Cost.

Each comparison was made by assigning a relative score to each pair of technologies. Each technology was compared to another technology and a score was given to the primary technology based on the following criteria. If the primary alternative is ranked higher than the compared alternative then the primary technology is given a score of one. If the alternatives are ranked equally then a score of zero is given to the primary alternative. The primary alternative is ranked less favorably than the compared alternative then the assigned score is negative one. The total score for each alternative is added across the row to provide a relative estimate of the applicability of the innovative technologies to the McCormick and Baxter site and a means of assessing how comparable the alternatives are to one another for a single treatment unit cell at the ten percent conceptual design level assumed for the ITE.

The information from the CSM report was further reviewed to assess the applicability of each technology to each focus area.

6.7.1 Former Waste Disposal Area (FWDA) - Willamette Cove

The Willamette Cove seep measured approximately 60 feet wide in 2003 and is approximately 320 feet from the barrier wall. The Willamette Cove seep area is characterized by more permeable geology than the TFA seep area

(Section 4.2.3.3 DEQ, 2005). The NAPL is likely migrating in a gravel layer that may have acted as a groundwater discharge zone (CSM Section 4.2.1.1, 2005) prior to the placement of the granular organoclay.

The subsurface consists of black sands (Section 4.2.3.3 DEQ, 2005). The most significant NAPL observations were within 1 to 3-feet below mud line with slight sheen to 5 feet below mud line in two locations (Section 4.2.1.1, 2005). The field evidence suggested that the Willamette Cove NAPL is behaving as an LNAPL.

Ozone-based ISCO is the most appropriate innovative technology for the FWDA area due to the limited presence of NAPL observed and the potential of ISCO to reduce NAPL levels to below residual saturation while providing treatment of groundwater and saturated soils. Cold water and hot water flooding as well as ERH may also be used in this area although these technologies may be limited by the in flow of water from the river through the target zone. Extraction–only technologies may also be effective for limiting NAPL discharge to Willamette Cove.

6.7.2 Evaluation for Former Tank Farm Area (TFA)

The TFA seep area measured approximately 225 feet wide in 2003 and is located along the beach area of the TFA. The distance from the TFA seep to the barrier wall is approximately 100 feet. The lithology of the TFA is similar to the FWDA except that a continuous confining layer was observed in the 15 probes advanced in the area in 2004 (Section 4.2.3.2 DEQ, 2005).

NAPL saturated sands were observed in three probe locations near the river in the interval between 10.5 and 13 feet below mud line (-2.6 to -5.1 feet NGVD). The NAPL was observed on top of a silt confining layer that extends from 13 to 19.5 feet below mud line (-5.1 to -11.6 feet NGVD). Visual evidence of NAPL decreased significantly below the silt layer suggesting that the NAPL is behaving as a DNAPL in this area. Additional NAPL was observed in wood debris beginning 7 feet above the silt layer and coincident with the water table in probes advanced further inland suggesting some LNAPL-like behavior and discontinuous DNAPL at shallower elevations. Probes advanced along the barrier wall had less visual evidence of NAPL suggesting that the barrier wall has cut-off the NAPL source in this area.

If it is determined that an innovative technology is required, the subsurface characteristics would suggest that ERH or flooding technologies would be better innovative technologies for the TFA area than ozone-based ISCO. Injecting ozone into the contacts between sands and silts may require closer well spacings than normal increasing the cost of the approach. ERH is not sensitive to subsurface heterogeneities such as stratigraphic contacts and wood debris. Flooding technologies are well suited to the geology of the TFA and NAPL distribution. Extraction-only approaches may also be effective in the TFA although the topography of the silt layers may limit the effectiveness of DNAPL extraction recovery as compared to cold or hot water flooding or ERH.

6.7.3 Additional Feasibility Concerns

The ITE identified five primary feasibility concerns beyond the scope of this ITE that should be resolved prior to a decision to implement an innovative technology. These are:

1. Because of the proximity of the river and the relatively high hydraulic conductivity of the sediments suggest that a detailed hydraulic evaluation is needed prior to implementing either flooding technique or ERH to account for fluctuating head conditions in the river to minimize potential for hydraulic control failure and subsequent NAPL mobilization to the river. Mobilization of NAPL and constituents to the river could result in increased threat to endangered salmonids and other sensitive receptors in the river;
2. Implementation of ISCO in FWDA would most likely be in a barrier configuration due to the sensitivity of the railroad trestle and underground utilities in the area to disturbances. Directional borings would be

required to assess the area under the trestle and additional design would be required to safeguard the underground utilities from ozone;

3. Implementation of ERH in the TFA focus area may require more electricity than estimated due to in flow of cold water from the river. A more detailed thermal evaluation is required to confirm that target temperatures can be reached and maintained;
4. Confirmation that the hydraulic control associated with either hot water flooding or ERH would prevent a violation of temperature based water quality standard in the river (Willamette River Total Maximum Daily Load); and
5. Hot water flooding, ISCO and ERH add energy to the subsurface and would require appropriate hazard analysis and modification of site procedures to minimize the implementation risk to site workers.

7.0 COST-BENEFIT ANALYSIS

The relative costs and benefits for each technology are shown in Table 7. The estimated benefit is based on the range of expected NAPL recovery efficiencies and operational durations shown on the technology characteristics tables and from the calculations for the time for NAPL depletion and life expectancy of the sediment cap augmented with granular organoclay (Appendix B). The costs are based on the technology cost estimates (Tables 2-5), cost estimates for seep repair and single-phase extraction (Tables B-1 through B-4, Appendix B), estimate of NAPL present in each flow path (Tables B-5 and B-6, Appendix B) and NAPL recovery efficiencies for the various alternatives.

7.1 NAPL Recovery Efficiencies and Effect on Cap Life

The expected NAPL recovery efficiencies shown on the technology characteristics tables (Tables 2 to 5) were used to calculate the initial oil saturation (Sro) input for the CSM NAPL Flow Calculations (Table B-5 presented in Appendix B) to evaluate the relative benefit for each technology. If a particular technology's NAPL removal efficiency (shown on Tables 2 to 5) reduced NAPL saturations to below the residual saturation (the minimum saturation required for NAPL mobility) then the technology completely removed mobile NAPL; future NAPL discharge is expected to be eliminated and is noted as zero. Flow paths 1 and 6 from the CSM Flow Calculations were evaluated for each of the four retained innovative technologies and single-phase extraction.

Cold water flooding may result in residual mobile NAPL in isolated locations. Hot water flooding is expected to remove mobile NAPL and reduce the residual saturation of NAPL to lower levels than cold water flooding. Ozone-based ISCO is also expected to remove all mobile NAPL; however, there is potential that isolated mobile NAPL will remain after treatment if subsurface heterogeneity is larger than expected. ERH is expected to have the best performance with respect to NAPL recovery and highest likelihood of eliminating mobile NAPL.

The expected life of the granular organoclay caps should increase as a result of implementation of an innovative remediation technology. Implementation risks such as displacement of NAPL towards the granular organoclay cap(s) are not included in this evaluation. The NAPL recovery efficiencies for innovative technologies are expected to range from 22 to 99.99 percent. In most cases, implementation of an innovative technology would eliminate NAPL mobility. The granular organoclay's design life for an infinite NAPL source ranges from 7.3 years in the TFA to 515 years in Willamette Cove based on the No Further Action scenario for the areas outside the barrier wall (Table 7 supported by Appendix B, Tables B-5 and B-6). While for the current condition, no extraction scenario, the estimated time for the finite source of mobile NAPL along the respective flowpaths to deplete itself to the River in the TFA is 5.3 years and in the FWDA is 130 years. Thus, although additional removal of NAPL either through continued single-phase extraction or an innovative technology would eliminate or reduce the NAPL mobility, the current remedy is predicted to effectively prevent upland sources of NAPL from migrating to the River.

7.2 COST-BENEFIT ANALYSIS

The estimated costs for the technologies are presented in Table 7. For the innovative technologies, these costs are based on the innovative cost estimates in Tables 2-5. These costs are not based on site specific experience, and thus are +50/-30% estimates. For the single-phase extraction, these costs are based on the actual cost for NAPL recovery between January 2004 and June 2005, and thus very reliable. For comparison to the retained innovative technologies, the duration of single phase extraction was assumed to be the corresponding estimated depletion time for remaining mobile NAPL by focus area as shown on Table 7.

For the current condition (no extraction), the cost to repair the sediment cap was included. The back-up for those calculations are presented in Tables B-1 and B-2 of Appendix B. These costs are based on actual site experience and thus are reliable estimates. The size of the sediment cap repair is an estimate based on the size of the seeps and assuming that the breakthrough would occur in a sub area of the granular organoclay portion of the sediment cap. The organoclay blanket scenario for the low end repair would be utilized in a small break-through while additional pure granular organoclay placement would be used if there were break-through over a larger area or at a higher NAPL flow rate.

8.0 CONCLUSIONS

The ITE was conducted to identify the most promising innovative remediation technologies that are feasible when used in combination with other site remedies and evaluate the benefit of applying one or a combination of these technologies to the current remedy to increase to the life expectancy of the sediment cap at the M&B site. A generalized approach was used that identified cost, performance, and implementation factors that may affect decisions related to innovative and on-going remediation activities for the area outside the barrier wall.

The results of the ITE suggest that if an innovative technology were selected for use at the site, ISCO with ozone in the FWDA, and either of the flooding technologies or ERH in the TFA show promise for the removal or destruction of NAPL to levels that will reduce NAPL mobility (i.e., reduce NAPL depletion time) and reduce uncertainties with the functional life of the granular organoclay and characterizations of the seep locations. The ITE results are qualified as conceptual, because data gaps exist for each of the innovative technologies that limit the estimates of performance and cost to plus 50 percent and minus 30 percent.

The results of the cost-benefit analysis and CSM NAPL mobility calculations suggest that the current condition is the most feasible alternative. When viewed in comparison to costs for repair and replenishment of the organo-clay component of the sediment cap, the costs for implementing an innovative technology in either the FWDA or TFA focus areas are high. This is especially true in light of the estimate that the functional life of the sediment cap exceeds the depletion time for the remaining mobile NAPL (DEQ, 2005). Thus, there is uncertainty whether the cap would ever need to be repaired due to NAPL break-through along these flow paths. Furthermore, continued NAPL recovery using the current method of manual single-phase extraction is inexpensive, and although it does not appear to provide significant benefit, it does remove NAPL. Continued optimization of the recovery techniques and new recovery-specific wells would likely further improve recovery efficiency. As such, NAPL recovery should continue until the recovery curve becomes asymptotic and additional recovery is not cost effective.

9.0 LIMITATIONS

We have prepared this report for use by the DEQ, their authorized agents and regulatory agencies. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

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10.0 REFERENCES

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TABLE 1
INITIAL SCREENING OF INNOVATIVE TECHNOLOGIES
McCORMICK AND BAXTER INNOVATIVE TECHNOLOGY EVALUATION FOR NAPL RECOVERY
PORTLAND, OREGON

Innovative Technology and Example Deployments at Creosote Sites	Description	Advantages	Disadvantages	Screening Comments
Organoclay Sediment Cap and Manual Recovery -McCormick and Baxter, Portland, Oregon	Soil cap, barrier wall, multilayer sediment cap with organoclay, soil removals, and NAPL recovery.	Known cost.	Some NAPL mobility potential remains. Absorptive organoclay media may require replacement.	Current condition, threat of NAPL migration to the Willamette River has been reduced significantly.
No Innovative Technologies Used To Date -Federal Creosote Company, Somerset County, New Jersey -American Creosote Works, Winnfield, Louisiana -Madisonville Creosote Works, Madisonville, Louisiana -Garland Creosoting, Longview, Texas -Conroe Creosoting, Conroe, Texas -Cascade Pole Company, Olympia, Washington	No innovative technologies were employed at these sites. Remediation activities commonly included excavation, stabilization, and/or installation of containment technologies such as walls (slurry and/or sheet pile), monitored natural attenuation and/or groundwater/NAPL extraction systems.	Not applicable	Not applicable	Provided for context only. Comparison of each site to McCormick and Baxter is outside the scope of this initial screening
Dual-Phase Extraction (DPE) or Bioslurping	DPE recovers LNAPL, groundwater, and vapors from an extraction well with an adjustable drop tube. The tube is connected to a high vacuum pump and the drop tube is placed at the LNAPL water interface. When the LNAPL/water level declines in response to pumping, the slurp tube begins vapor extraction. As vapor is extracted, airflow is induced through the unsaturated zone until the water level rises and the cycle begins again.	Extraction-only technology minimizes risk to river. Works well for LNAPL, volatile compounds, and dissolved fraction. Enhances aerobic biological activity for degradable fraction by inducing air flow.	Creosote is not volatile or readily treated by biodegradation. Biofouling of well screen may occur because of localized aeration. Does not improve treatment of the saturated zone as compared to groundwater/NAPL extraction. Recovered LNAPL requires off-site disposal. Will not recover denser than water NAPL (DNAPL) fraction. Vacuum equipment requires regular operation and maintenance. Relatively slow process.	Does not address DNAPL, will only address LNAPL and volatile fraction. Requires permanent infrastructure. Expected design life 20 to 100 years.
In Situ Bioremediation (Hydrogen Peroxide-based) -Libby Superfund, Libby, Montana (soil piles and MNA) -Creosote site, Pensacola, Florida (MNA)	Involves injection of oxygen-amended water into the subsurface by injection wells or trenches. Hydrogen peroxide is used as the oxygen generator, thus reducing oxygen-limitation on biodegradation rates.	Destroys dissolved contaminant mass and increases mass flux from NAPL to groundwater. Relatively simple to implement. Proven at several sites.	Biodegradation is limited by rate of oxygen transfer and toxicity of creosote. Higher cost than other air-based bioremediation. Correct concentrations of hydrogen peroxide must be considered to maintain biomass. Interphase mass transfer is required from NAPL to dissolved phase prior to bioremediation prolonging expected treatment duration. Limited direct effect on NAPL.	Does not mobilize NAPL. Likely to fail due to toxicity of creosote and chlorophenols. Expected design life 30 to 100 years.
Cold Water Flooding -Louisiana Facility -Union Pacific Tie Plant, Laramie, Wyoming -Union Pacific Tie Plant, The Dalles, Oregon	Cold water flooding increases hydraulic gradients to mobilize NAPL toward a recovery system. Injection-extraction well pairs/configurations are used. Induced hydraulic gradients must exceed capillary and density forces in order to mobilize NAPL above residual saturation. Above ground separation equipment (coalescing plate separators, walnut shell filters, and granular activated carbon (GAC) are common).	Increases recovery rate with high number of pore volume exchanges. Accelerates cleanup time over conventional recovery-only systems. Proven to enhance oil production in petroleum industry.	Potential for spreading of dissolved contaminants. Successful implementation is very site-specific and requires knowledge of geologic conditions for proper location of injection and recovery wells. Requires regular operation and maintenance of equipment. Off-site disposal of recovered NAPL. Recovery limited to mobile NAPL.	Will not recover below residual saturations. Less effective than hot water flooding due to NAPL properties. Expected design life 5 to 50 years.
Hot Water Flooding -MacGillis & Gibbs Co./Bell Lumber & Pole Co, New Brighton, Minnesota -Brodhead Superfund Site, Stroudsburg, Pennsylvania for Manufactured Gas Plant residuals	Increases hydraulic gradients and reduces viscosity to mobilize NAPL toward a recovery system. Injection-extraction well pairs/configurations are used. Above ground separation equipment (coalescing plate separators, walnut shell filters, and advanced oxidation processes (AOP) or membrane treatment are common). Cold water flood is conducted prior to hot water.	Increases recovery rate with lower pore volume exchange rate than cold water flush. Accelerates cleanup time over conventional recovery-only or cold water flushing. Reduces residual saturation of NAPL. Recovers NAPL and dissolved fractions. Slower heating process than steam, resistive or conductive heating.	Increases aqueous solubility of creosote components, some of which are solid at ambient temperatures. Successful implementation is very site-specific and requires knowledge of geologic conditions for proper location of injection and recovery wells. Requires robust treatment equipment, regular operation and maintenance, and insulated or heated conveyance piping designed to avoid crystallization of creosote. Fuel costs are significant. Off-site disposal of recovered NAPL.	Hot water flooding shows promise. Design life 4 to 10 years. Lowest risk thermal technology.
Surfactant or Cosolvent Flushing -South Cavalcade Street, Houston, Texas	Flushing treatment zone with surfactants or cosolvents to increase the apparent aqueous solubility of NAPL components. Some viscosity reduction and increase in NAPL mobility into recovery system may be expected.	Mobilizes NAPL to improve recovery rate. Requires relatively simple infrastructure. Accelerates cleanup time over conventional pump-and-treat systems.	Increases apparent aqueous solubility of creosote components. Requires many pore volume flushes to dissolve NAPL. NAPL and amendment separation above ground likely required. Disposal costs for recovered amendment can be large. Extensive pre-design data required. Potential for spreading of NAPL if cosolvents are used. Potential higher groundwater concentrations if surfactants are used. Residual amendment likely to remain in groundwater.	Likely more expensive than water flooding alone due to amendment costs. Secondary risk from residual amendments and higher aqueous concentrations after treatment. Expected design life 3 to 20 years.
In-Situ Chemical Oxidation (ISCO) -Ecotype Pond Site, Windsor, California (ozone gas)	Chemical destruction of NAPL components and NAPL mass. Ozone gas is sparged through NAPL zone on moderate well spacing. Some gaseous displacement of NAPL and/or subsequent volatilization either ozone sparging or catalyzed hydrogen peroxide injection may occur. Catalyzed hydrogen peroxide, and activators, are injected into saturated zone on close spacing. Two to three treatment solutions are used by various vendors.	Rapid chemical destruction of NAPL components. Little to no recovered NAPL is handled or requires disposal. Biodegradability is improved and oxygen is delivered.	Large chemical demand expected due to NAPL mass. Bench scale testing is required for dosage. NAPL mobilization may occur if injection pressure is high. Partial oxidation products require attenuation by follow-on biological processes. Ozone equipment has moderate capital costs. Two to four peroxide injections may be required.	Mass destruction, fast treatment, and secondary biological treatment warrant further consideration. Design life is 1 to 10 years.
Conductive Heating (In Situ Thermal Desorption) -Southern California Edison Wood Treatment Facility, Alhambra, California (proposed)	Heating blankets and/or steam loops (thermal wells) increase the temperature of treatment zone. Unsaturated soils may be heated until contaminants are thermally degraded, the saturated zone is heated to boiling temperature of water. Vapor collection is normally performed but hydrous pyrolysis oxidation (HPO) may also be achieved in unsaturated zone.	Controlled heating rate. No injected fluids. Generates steam in situ and causes hydrous pyrolysis oxidation (HPO). Dries soil and increases air permeability. Very high temperatures can be achieved in unsaturated zone. Effective for fine grained soils. Can reduce residual saturation of NAPL and contaminant concentrations as a result of lower residual NAPL levels.	Heat penetration distance requires close spacing of heat wells and limited vertical penetration. Increases aqueous solubility of creosote components, some of which are solid at ambient temperatures. High vapor pressure PAHs may not vaporize. HPO temperature may not be achieved in saturated zone. Monitoring wells in the treatment area must be replaced with metallic wells with cement or API Class G grouts, depending on target temperature. Vapor extraction or total fluids recovery may be required to collect mobilized NAPL, dissolved fraction or volatilized components. Requires robust treatment equipment, regular operation and maintenance, and insulated or heated conveyance piping designed to avoid crystallization of creosote. Surface vapor barrier required.	Lowest promise thermal technology due to high vapor pressure of PAH, potential for downward migration of mobilized DNAPL and difficulty installing wells at close spacing along shoreline. More common for polychlorinated biphenyl sites than creosote. Thermal blanket would have limited effect, large number of thermal wells would be needed resulting in high relative cost to other thermal options. Design life 1 to 10 years.

TABLE 1
INITIAL SCREENING OF INNOVATIVE TECHNOLOGIES
McCORMICK AND BAXTER INNOVATIVE TECHNOLOGY EVALUATION FOR NAPL RECOVERY
PORTLAND, OREGON

Innovative Technology and Example Deployments at Creosote Sites	Description	Advantages	Disadvantages	Screening Comments
Electrical Resistive Heating -No creosote sites identified	Electrical resistive heating most commonly involves six-phase power applied to seven electrodes in a hexagonal pattern. Sheet pile walls have also been used as electrodes. The electricity resistively heats up the soil and vaporizes soil moisture creating steam. Mobilizes NAPL and reduced residual saturations. The electrodes are also soil vapor extraction wells to collect the steam and NAPL. The vapor is run through a condenser, and liquids that result are treated with separators, filters, and AOP.	Rapid. Can treat low permeability soils. High mass removal rate and efficiency. Can reduce residual saturation of NAPL and contaminant concentrations as a result of lower residual NAPL levels. Effective for fine grained soils.	Increases aqueous solubility of creosote components, some of which are solid at ambient temperatures. Requires experienced vendor to address health and safety concerns. Hexagonal vertical electrode systems perform best with spacing less than 30 feet. Mobile power plant required. Requires condenser. Requires robust treatment equipment, regular operation and maintenance, and insulated or heated conveyance piping designed to avoid crystallization of creosote and vapor collection system. Monitoring wells in the treatment area must be replaced with metallic wells with cement or API Class G grouts, depending on target temperature.	Shows promise. Sheet piles may be used as electrodes. Less aggressive than steam injection because extraction only. More aggressive than hot water flood or ISCO Design life 1 to 10 years.
Steam Injection -Port of Ridgefield (Former Pacific Wood Treating), Clark County, Washington -Visalia Superfund Site, Visalia, California -Wycoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington	Steam injection reduces the viscosity of NAPL, displaces groundwater and NAPL, and HPO. Steam and air are injected until the target temperature is achieved while total fluids are recovered. The steam is allowed to condense and the groundwater returns to the heated zone. Contaminants, condensed steam, and oxygen mix causing HPO of additional contaminant. The process is repeated if necessary.	Proven successful for creosote remediation. Fast mass recovery and follow-on treatment. Rapid pressure cycling may be performed to optimize NAPL recovery. Can reduce residual saturation of NAPL and contaminant concentrations as a result of lower residual NAPL levels. Increases bioremediation by thermophyllic microorganisms. Biodegradability is improved and oxygen is delivered. May achieve MCLs in addition to remove NAPL.	Increased pressure may drive water through a slurry wall, vents may be required. Increases aqueous solubility of NAPL components. Steam generation plant required. Increases aqueous solubility of creosote components, some of which are solid at ambient temperatures. Requires robust treatment equipment, regular operation and maintenance, and insulated or heated conveyance piping designed to avoid crystallization of creosote including vapor collection system. Initial startup cost could be high. Partial oxidation products require attenuation by follow-on biological processes. Monitoring wells may need to be replaced with metallic wells. Cement or API Class G grouts may be required for wells.	May be difficult to implement on shoreline. Design life 1 to 10 years. Proven effective at other creosote sites. May drive NAPL toward river, therefore technology was eliminated.
Dynamic Underground Stripping -No creosote sites identified.	Dynamic underground stripping (DUS) is a technique that combines steam injection and electrical resistive heating. Optimized for bulk mass removal and HPO that destroys residual contaminant mass. Enhanced bioremediation has been observed.	Fast. Most effective for volatile and semi-volatile compounds. LNAPL and DNAPL are treated. Brings two technologies to bear simultaneously allowing close process control and changing site conditions. Cleanup-up times are reduced from decades to years. Can reduce residual saturation of NAPL and contaminant concentrations as a result of lower residual NAPL levels.	Increased pressure may drive water through a slurry wall, vents may be required. Increases aqueous solubility of creosote components, some of which are solid at ambient temperatures. Costs are higher than steam or electrical resistive heating alone. Requires planning to avoid negative interaction between equipment used for different technologies. Normally applied when a less permeable layer is below the target zone however a lower heated zone may prevent downward migration. Requires robust treatment equipment, regular operation and maintenance, and insulated or heated conveyance piping designed to avoid crystallization of creosote including vapor collection. Monitoring wells may need to be replaced with metallic wells. Cement or API Class G grouts may be required for wells.	Risk to river unacceptable due to increased mobilization potential (two heat sources used.) Design life 1 to 10 years. High equipment and operational costs.

Notes:
Shading represents remedial actions eliminated from consideration
DPE = dual phase extraction
GAC = granular activated carbon
NAPL = non-aqueous phase liquid
MCL = maximum contaminant level
MNA = monitored natural attenuation
DNAPL = more dense than water NAPL
LNAPL = less dense than water NAPL
ISCO = in situ chemical oxidation
AOP = advanced oxidation processes
HPO = hydrous pyrolysis oxidation
DUS - dynamic underground stripping

TABLE 2
DEPLOYMENT CHARACTERISTICS FOR COLD WATER FLOODING
McCORMICK AND BAXTER
PORTLAND, OREGON

Treatment Configuration

Description of Approach	Water flooding involves injection and extraction of groundwater to increase gradients and push NAPL towards recovery wells. The unit processes would include injection of water, extraction of NAPL and groundwater, coalescing plate separators for separating NAPL from groundwater, granular filtration with walnut shell media, and a treatment using granular activated carbon (GAC). The unit cell for water flooding would involve split drive well configuration, i.e. two extraction wells for each injection well, extraction wells along shoreline and barrier wall, injection wells along centerline between extraction wells. Specific to the site, extraction wells would be placed along shoreline and barrier wall and injection wells along center.

Unit Cell Dimensions	**FWDA**	**TFA**	**Units**
Width - Parallel to shoreline	100	125	FEET
Length - Transverse to shoreline	75	80	FEET
Target Thickness	26	16	FEET
Area	0.17	0.23	ACRES
Well Configuration	Split line drive	Split line drive	(Grid, Line drive, Five-spot, Four-spot, Hexagonal)
Well Details	**Number**	**Number**	**Description**
Extraction Locations	8	8	Vertical 4-inch 0.020-inch, Sch 40 PVC, API Class G grout
Injection Locations	2	2	Vertical 4-inch 0.020-inch, Sch 40 PVC, API Class G grout
Monitoring Wells	3	2	Vertical 2-inch 0.010-inch, Sch 40 PVC
Well Screen Interval	**FWDA**	**TFA**	**Units**
Injection Wells	10 to -15	10 to -15	FEET NGVD
Extraction Wells	0 to -25	0 to -15	FEET NGVD
Monitoring Wells - Shallow	0 to -12	0 to -15	FEET NGVD
Monitoring Wells - Intermediate	-13 to -25	–	FEET NGVD
Design Parameters	**FWDA**	**TFA**	**Units**
Injected materials	Treated groundwater	Treated groundwater	
Extracted materials	NAPL and groundwater	NAPL and groundwater	
Design Hydraulic Gradient	0.2	0.2	UNITLESS
Extraction well flow rate	11	11	GPM
Injection well flow rate	44	44	GPM
Treatment system flow rate	88	88	GPM

Deployment Characteristics

Assembly	Description	Units	Range Low	Range High	Expected
NAPL Recovery Efficiency		PERCENTAGE	22	65	39
Unit Cells per Focus Area	FWDA	PER	1	8	4
	TFA	PER	1	6	3
Duration	Design	WEEKS	12	36	12
	Mobilization	WEEKS	1	6	4
	Installation	WEEKS	2	9	4
	Operations	MONTHS	24	60	48

Cost Assemblies

Cost Type	Description	Units	Range Low	Range High	Expected
Labor	Design	FTE	0.23	2.08	0.46
	Mobilization	FTE	0.04	0.46	0.23
	Installation	FTE	0.08	1.04	0.23
	Operations	FTE/YEAR	1.00	3.00	2.00
Well Installation and Develo	Extraction - GW and NAPL	$	$4,800	$13,440	$8,320
	Injection	$	$2,200	$5,600	$3,640
	Monitoring	$	$7,070	$7,560	$4,680
Capital Costs[1]	Walnut Shell Granular Filter	$	$150,000	$180,000	$175,000
	Mechanical Installation	$	$30,000	$123,000	$87,500
	Treatment Equipment Building	$	$60,000	$90,000	$75,000
	Controls	$	$25,000	$65,000	$45,000
	Electrical Installation	$	$34,000	$190,000	$35,000
	Well Pumps	$	$24,000	$44,000	$34,000
	Granular Activated Carbon Systen	$	$22,740	$36,760	$26,300
	Air/Compressor and Dryer	$	$15,000	$30,000	$25,000
	Coalescing Plates Separators	$	$20,000	$30,000	$25,000
	Low Shear Transfer Pump	$	$12,000	$23,000	$18,000
	On site storage of Creosote	$	$2,000	$3,500	$2,500
Well Installation and Capital Cost Total			**$408,810**	**$841,860**	**$564,940**
Operating Costs	Electricity	KW	20	33	26
	Electricity	$/KWH	$0.183	$0.183	$0.183
	Electricity	$/YEAR	$31,260	$52,100	$41,680
	Consumables	$/YEAR	$2,500	$7,000	$4,500
	Lqd Phase Granular Activated Car	$/YEAR	$23,700	$122,640	$69,300
	Off-site Disposal of Creosote	$/POUND	$0.15	$0.25	$0.20
	Off-site Disposal of Creosote	$/YEAR	$4,765.88	$7,943.13	$6,354.50
	Maintenance Supplies	$/YEAR	$1,000	$6,000	$3,000
Unit Cell Operating Total for Total Duration of Operation			**$79,052**	**$365,216**	**$222,138**

Notes:
[1] Capital costs are for single unit cell comparisons only. With additional unit cells, the capital costs could be shared therefore decreasing the capital cost per unit cell.
GPM - Gallons per Minute
FTE - Full Time Equivalents
KWH - Kilowatt Hour

TABLE 3
DEPLOYMENT CHARACTERISTICS FOR HOT WATER FLOODING
McCORMICK AND BAXTER
PORTLAND, OREGON

Treatment Configuration					
Description of Approach	Hot water flooding involves injection and extraction of heated groundwater to increase gradients and decrease NAPL viscosity to push NAPL towards recovery wells. Prior to hot water flooding, cold water flooding is often performed, when NAPL recovery slows hot water flooding follows. The unit processes would include injection of heated water, extraction of NAPL and groundwater, coalescing plate seperators for seperating NAPL from groundwater, granular filtration with walnut shell media, and a tertiary treatment using ozone-peroxide advanced oxidation. The unit cell for water flooding would involve split drive well configuration, i.e. two extraction wells for each injection well, extraction wells along shoreline and barrier wall, injection wells along centerline between extraction wells. Specific to the site, extraction wells would be placed along shoreline and barrier wall and injection wells along center.				
Unit Cell Dimensions		**FWDA**	**TFA**		
Width - Parallel to shoreline		100	125	FEET	
Length - Transverse to shoreline		75	80	FEET	
Target Thickness		26	16	FEET	
Area		0.17	0.23	ACRES	
Well configuration		Split line drive	Split line drive	(Grid, Line drive, Five-spot, Four-spot, Hexagonal)	
Well Details		**Number**	**Number**	**Description**	
Extraction Locations		8	8	Vertical 4-inch 0.020-inch, Sch 40 PVC, API Class G grout	
Injection Locations		2	2	Vertical 4-inch 0.020-inch, Sch 40 CPVC, API Class G grout	
Monitoring Wells		2	2	Vertical 2-inch 0.010-inch, Sch 40 PVC	
Well Screen Interval		**FWDA**	**TFA**		
Injection Wells		10 to -15	10 to -15	FEET NGVD	
Extraction Wells		0 to -25	0 to -15	FEET NGVD	
Monitoring Wells - Shallow		0 to -12	0 to -15	FEET NGVD	
Monitoring Wells - Intermediate		-13 to -25	–	FEET NGVD	
Design Parameters		**FWDA**	**TFA**		
Injected materials		Heated Groundwater	Heated Groundwater		
Extracted materials		NAPL and Groundwater	NAPL and Groundwater		
Design Hydraulic Gradient		0.2	0.2	UNITLESS	
Temperature - Injected Groundwater		180	180	F	
Boiler Capacity				BTU PER HR	
Extraction well flow rate		11	11	GPM	
Injection well flow rate		44	44	GPM	
Treatment system flow rate		88	88	GPM	

Deployment Characteristics					
			Range		
Cost Type	**Description**	**Units**	**Low**	**High**	**Expected**
NAPL Recovery Efficiency		PERCENTAGE	43	82	53
Unit Cells per Focus Area	FWDA	PER	1	8	4
	TFA	PER	1	6	3
Duration	Design	WEEKS	12	36	12
	Mobilization	WEEKS	1	6	4
	Installation	WEEKS	2	9	4
	Operations	MONTHS	12	48	36

Cost Assemblies					
			Range		
Cost Type	**Description**	**Units**	**Low**	**High**	**Expected**
Labor	Design	FTE	0.69	4.15	0.92
	Mobilization	FTE	0.08	0.46	0.31
	Installation	FTE/YEAR	0.15	0.50	0.38
	Operations	FTE/YEAR	1.00	4.00	2.00
Well Installation	Extraction - GW and NAPL	$	$4,800	$13,440	$8,320
	Injection - Hot Water	$	$3,000	$7,840	$5,200
	Monitoring	$	$1,400	$7,560	$4,680
Capital Costs[1]	Ozone-Peroxide AOP System	$	$65,000	$350,000	$216,000
	Walnut Shell Granular Filter	$	$150,000	$180,000	$175,000
	Mechanical Installation	$	$30,000	$123,000	$87,500
	Treatment Equipment Building	$	$60,000	$90,000	$75,000
	Boiler and Heat Exchanger	$	$43,000	$79,500	$66,000
	Controls	$	$25,000	$65,000	$45,000
	Electrical Installation	$	$34,000	$190,000	$35,000
	Well Pumps	$	$24,000	$44,000	$34,000
	Air/Compressor and Dryer	$	$15,000	$30,000	$25,000
	Coalescing Plates Separators	$	$20,000	$30,000	$25,000
	Low Shear Transfer Pump	$	$12,000	$23,000	$18,000
	On site storage of Creosote	$	$2,000	$3,500	$2,500
Well Installation and Capital Cost Total			**$489,200**	**$1,236,840**	**$822,200**
Operating Costs	Electricity	KW	29	49	39
	Electricity	$/KWH	$0.183	$0.183	$0.183
	Electricity	$/YEAR	$46,890	$78,150	$62,520
	Natural Gas Usage	CFD	853	1,706	1,137
	Natural Gas Cost	$/YEAR	$3,277	$32,459	$13,733
	Consumables	$/YEAR	$13,403	$32,550	$16,000
	Off-site Disposal of Creosote	$/POUND	$0.15	$0.25	$0.20
	Off-site Disposal of Creosote	$/YEAR	$4,765.88	$7,943.13	$6,354.50
	Maintenance Supplies	$/YEAR	$1,000	$6,000	$3,000
Unit Cell Operating Total for Total Duration of Operation			**$69,336**	**$628,409**	**$304,822**

Notes:
[1] Capital costs are for single unit cell comparisons only. With additional unit cells, the capital costs could be shared therefore decreasing the capital cost per unit cell.
GPM - Gallons Per Minute
FTE - Full Time Equivalents
KWH - Kilowatt Hour

TABLE 4
DEPLOYMENT CHARACTERISTICS FOR IN SITU CHEMICAL OXIDATION
McCORMICK AND BAXTER
PORTLAND, OREGON

Treatment Configuration

Description of Approach

In Situ Chemical Oxidation (ISCO) involves the chemical destruction of NAPL components and mass within the subsurface. Following a bench scale test, ozone gas is sparged through the NAPL zone through numerous sparge point wells. The ozone is a non-selective oxidant that can destruct the NAPL components. The reactions can produce gaseous products and excess ozone that would be captured through a soil vapor extraction system and treated with an ozone deconstruction catalyst. Little to no recovered NAPL is handled or disposed of since NAPL is destroyed in situ. ISCO well design would include a modified five spot configuration with numerous, moderately spaced injection sparge points surrounded by SVE wells on the exterior. ISCO may also increase aerobic biological treatment with the increase in available oxygen within the subsurface.

Unit Cell Dimensions	**FWDA**	**TFA**	**Units**
Width- Parallel to shoreline	120	120	FEET
Length - Transverse to shoreline	120	120	FEET
Target Thickness	26	16	FEET
Area	0.33	0.33	ACRES

Well configuration	Five-spot	Five-spot	(Grid, Line drive, Five-spot, Four-spot, Hexagonal)
Well Details	**Number**	**Number**	**Description**
Extraction Locations	7	7	Vertical 4-inch 0.020-inch, Sch 40 PVC, API Class G grout
Injection Locations	10	10	Vertical 2-inch 0.020-inch, 316 SS, API Class G grout
Monitoring Wells	2	2	Vertical 2-inch 0.010-inch, Sch 40 PVC

Well Screen Interval	**FWDA**	**TFA**	**Units**
Injection Wells - Shallow	-9 to -12	-10 to -13	FEET NGVD
Injection Wells - Intermediate	-22 to -25	-12 to -15	FEET NGVD
Extraction Wells	-3 to -8	-3 to -8	FEET NGVD
Monitoring Wells - Shallow	0 to -12	0 to -15	FEET NGVD
Monitoring Wells - Intermediate	-13 to -25	–	FEET NGVD

Design Parameters	**FWDA**	**TFA**	**Units**
Injected materials	0.3 to 3% Ozone and Air	0.3 to 3% Ozone and Air	
Extracted materials	NONE	NONE	
Ozone Production	60	60	POUND PER DAY
Injection Flow Rate per Well	10	10	SCFM
Ozone to Air Boost Ratio	1:2	1:2	UNITLESS
Ozone Wells Operating at Once	3	3	WELLS

Deployment Characteristics

Cost Type	**Description**	**Units**	**Range Low**	**Range High**	**Expected**
NAPL Recovery Efficiency		PERCENTAGE	50	99.9	90
Unit Cells per Focus Area	FWDA	PER	1	16	4
	TFA	PER	1	8	2
Duration	Design	WEEKS	8	24	12
	Mobilization	WEEKS	1	6	4
	Installation	WEEKS	1	6	2
	Operations	MONTHS	12	36	24

Cost Assemblies

Cost Type	**Description**	**Units**	**Range Low**	**Range High**	**Expected**
Labor	Design	FTE	0.46	2.77	0.92
	Mobilization	FTE	0.08	0.46	0.31
	Installation	FTE/YEAR	0.08	0.50	0.19
	Operations	FTE/YEAR	0.50	2.00	1.00
Well Installation	Vapor Extraction	$	$4,800	$13,440	$8,320
	Injection Wells - Ozone	$	$13,000	$30,800	$23,400
	Monitoring	$	$1,400	$5,040	$3,120
Capital Costs[1]	Ozone Generation System (50 ppd)	$	$65,000	$350,000	$250,000
	Controls	$	$25,000	$65,000	$45,000
	Distribution Piping	$	$35,000	$55,000	$42,000
	Electrical Installation	$	$15,000	$35,000	$23,000
	Soil Vapor Extraction System	$	$15,000	$18,000	$17,500
	Soil Vapor Extraction Piping	$	$12,000	$17,000	$15,000
	Ozone Reducing Catalyst	$	$3,000	$15,000	$8,500
	Safety Equipment	$	$2,500	$8,500	$4,500
	Air Permit	$	$3,500	$7,500	$4,500
	Mechanical Installation	$	$2,000	$3,500	$2,500
	Equipment Foundation	$	$1,000	$3,500	$2,000
Well Installation and Capital Cost Total			**$198,200**	**$627,280**	**$449,340**
Operating Costs	Electricity	KW	36	60	48
	Electricity	$/KWH	$0.183	$0.183	$0.183
	Electricity	$/YEAR	$57,711	$96,185	$76,948
	Consumables	$/YEAR	$2,500	$7,000	$4,500
	Maintenance Supplies	$/YEAR	$1,200	$7,500	$5,000
Unit Cell Operating Total for Total Duration of Operation			**$61,411**	**$332,054**	**$172,896**

Notes:
[1] Capital costs are for single unit cell comparisons only. With additional unit cells, the capital costs could be shared therefore decreasing the capital cost per unit cell.
GPM - Gallons per Minute
FTE - Full Time Equivalents
KWH - Kilowatt Hour
SCM - Cubic Feet per Minute at Standard Temperature and Pressure

TABLE 5
DEPLOYMENT CHARACTERISTICS FOR ELECTRICAL RESISTIVE HEATING
McCORMICK AND BAXTER
PORTLAND, OREGON

Treatment Configuration	
Description of Approach	Electrical resistive heating involves the addition of electrodes to the subsurface to heat the subsurface, which has two end results: increasing gradients in order to decrease NAPL viscosity and to volatize NAPL constituents thereby reducing viscosity to mobilize NAPL towards SVE and NAPL recovery wells. Electrical resistive heating can eliminate residual saturation levels of NAPL. Electrodes and total fluids extraction wells are often placed in the same boring in a hexagonal well pattern with a center electrode/extraction well. The sheetpile walls may also be used as additional electrodes. The unit processes include heating the ground followed by vapor and total fluids extraction, vapor condensation, groundwater granular filtration with walnut shell media, and tertiary treatment using ozone-peroxide advanced oxidation along with vapor treatment by granular activated carbon (GAC).

Unit Cell Dimensions	FWDA	TFA	Units
Width - Parallel to shoreline	112	112	FEET
Length - Transverse to shoreline	56	56	FEET
Target Thickness	26	16	FEET
Area	0.14	0.14	ACRES

Well configuration	Dual-Hexagonal	Dual-Hexagonal	(Grid, Line drive, Five-spot, Four-spot, Hexagonal)
Well Details	**Number**	**Number**	**Description**
SVE/Total Fluids Extraction Locations	12	12	Vertical 8-in boring, 2-in ss casing shot filled, API Class G grout
Monitoring Well Locations	2	2	Vertical 2-inch 0.010-inch, steel wells, API Class G grout
Thermocouple Locations	8	8	Vertical 1-inch direct buried, multi-level thermal couples

Well Screen Interval	FWDA	TFA	Units
Injection Wells	10 to -15	10 to -15	FEET NGVD
Extraction Wells	0 to -25	0 to -15	FEET NGVD
Monitoring Wells - Shallow	0 to -12	0 to -15	FEET NGVD
Monitoring Wells - Intermediate	-13 to -25	--	FEET NGVD
Thermocouples - Shallow	0 to -12	0 to -15	FEET NGVD
Thermocouples - Intermediate	-13 to -25	--	FEET NGVD

Design Parameters	FWDA	TFA	Units
Injected materials	Electricity	Electricity	
Extracted materials	Vapors	Vapors	
Electrode Power	74	74	KVA/Electrode
Design Hydraulic Gradient	1480	1480	UNITLESS
Temperature - Initial Heat Target	212	212	F
Temperature - Maintenance Factor	5	5	UNITLESS
Extraction well flow rate	80	80	SCFM
Extraction well flow rate	11	11	GPM
Treatment system flow rate	960	960	SCFM
Treatment system flow rate	132	132	GPM

Deployment Characteristics

Cost Type	Description	Units	Range Low	Range High	Expected
NAPL Recovery Efficiency		PERCENTAGE	99	99.99	99.9
Unit Cells per Focus Area	FWDA	PER	1	12	8
	TFA	PER	1	8	6
Duration	Design	WEEKS	8	24	12
	Mobilization	WEEKS	1	6	4
	Installation	WEEKS	3	6	4
	Operations	MONTHS	5	12	9

Cost Assemblies

Cost Type	Description	Units	Range Low	Range High	Expected
Labor	Design	FTE	0.17	0.35	0.23
	Mobilization	FTE	0.08	0.46	0.31
	Installation	FTE/YEAR	0.23	1.15	0.38
	Operations	FTE/YEAR	1.00	4.00	2.00
Well Installation	Vapor Extraction	$	$24,000	$73,920	$56,160
	Electrodes	$	$12,000	$31,360	$20,800
	Monitoring	$	$2,600	$8,160	$4,680
Capital Costs[1]	Walnut Shell Granular Filter	$	$150,000	$180,000	$175,000
	Ozone-Peroxide AOP System	$	$65,000	$350,000	$125,000
	Mechanical Installation	$	$30,000	$123,000	$87,500
	Electrical Installation	$	$35,000	$125,000	$75,000
	Treatment Equipment Building	$	$60,000	$90,000	$75,000
	Power Supply (6 - phase)	$	$45,000	$95,000	$70,000
	Coalescing Plates Separators	$	$25,000	$75,000	$59,000
	Electrical Installation	$	$34,000	$190,000	$50,000
Capital Costs[1] Cont.	Soil Vapor Extraction System	$	$25,000	$75,000	$45,000
	Controls	$	$25,000	$65,000	$45,000
	Well Pumps	$	$15,000	$66,000	$39,250
	Power Distribution System	$	$6,500	$65,000	$35,000
	Air/Compressor and Dryer	$	$15,000	$30,000	$25,000
	Low Shear Transfer Pump	$	$12,000	$23,000	$18,000
	Vapor Phase Granular Activated Ca	$	$11,160	$19,840	$16,200
	Soil Vapor Extraction Piping	$	$10,000	$35,000	$15,000
	On site storage of Creosote	$	$2,000	$5,500	$2,750
Well Installation and Capital Cost Total			**$604,260**	**$1,723,780**	**$1,039,340**
Operating Costs	Electricity	KW	151	251	201
	Electricity	$/KWH	$0.183	$0.183	$0.183
	Electricity	$/YEAR	$241,664	$402,774	$322,219
	Consumables	$/YEAR	$13,403	$32,550	$16,000
	Vapor Phase Granular Activated Ca	$/YEAR	$2,107	$17,520	$8,400
	Off-site Disposal of Creosote	$/POUND	$0.15	$0.25	$0.20
	Off-site Disposal of Creosote	$/YEAR	$3,536.47	$5,894.11	$4,715.29
	Maintenance Supplies	$/YEAR	$1,000	$6,000	$2,000
Unit Cell Operating Total for Total Duration of Operation			**$109,046**	**$464,738**	**$265,001**

Notes:
[1] Capital costs are for single unit cell comparisons only. With additional unit cells, the capital costs could be shared therefore decreasing the capital cost per unit cell.
GPM - Gallons per Minute
FTE - Full Time Equivalents
KWH - Kilowatt Hour

TABLE 6
COMPARATIVE EVALUATION OF INNOVATIVE TECHNOLOGIES
McCORMICK AND BAXTER
PORTLAND, OREGON

Comparison of:		Effectiveness				Long-term Reliability				Implementability				Threat Reduction				Cost				Score
	RAO	1 CWF	2 HWF	3 ISCO	4 ERH	1 CWF	2 HWF	3 ISCO	4 ERH	1 CWF	2 HWF	3 ISCO	4 ERH	1 CWF	2 HWF	3 ISCO	4 ERH	1 CWF	2 HWF	3 ISCO	4 ERH	
1 Cold Water Flood	+		-	-	-		0	-	-			+	+		-	-	-		+	+	+	-2
2 Hot Water Flood	+	+		+	0	+		+	0	0		+	+	+		0	0	-		-	0	6
3 In Situ Chemical Oxidation	+	+	+		0	+	0		0	-	-		0	+	0		0	+	+		+	6
4 Electrical Resistive Heating	+	+	0	0		+	0	0		-	-	0		+	0	0		-	0	-		0

Notes:

+ = The alternative is ranked higher than the compared alternative (score=1)
0 = The alternative is ranked equally with the compared alternative (score = 0)
- = The alternative is ranked less favorably than the compared alternative (score = -1)

Alternatives:
1 = Cold Water Flooding (CWF)
2 = Hot Water Flooding (HWF)
3 = In Situ Chemical Oxidation (ISCO)
4 = Electrical Resistive Heating (ERH)

RAO = Remedial Action Objective
Remove NAPL from active seep areas with potential to discharge to river.

TABLE 7
COST-BENEFIT ANALYSIS
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

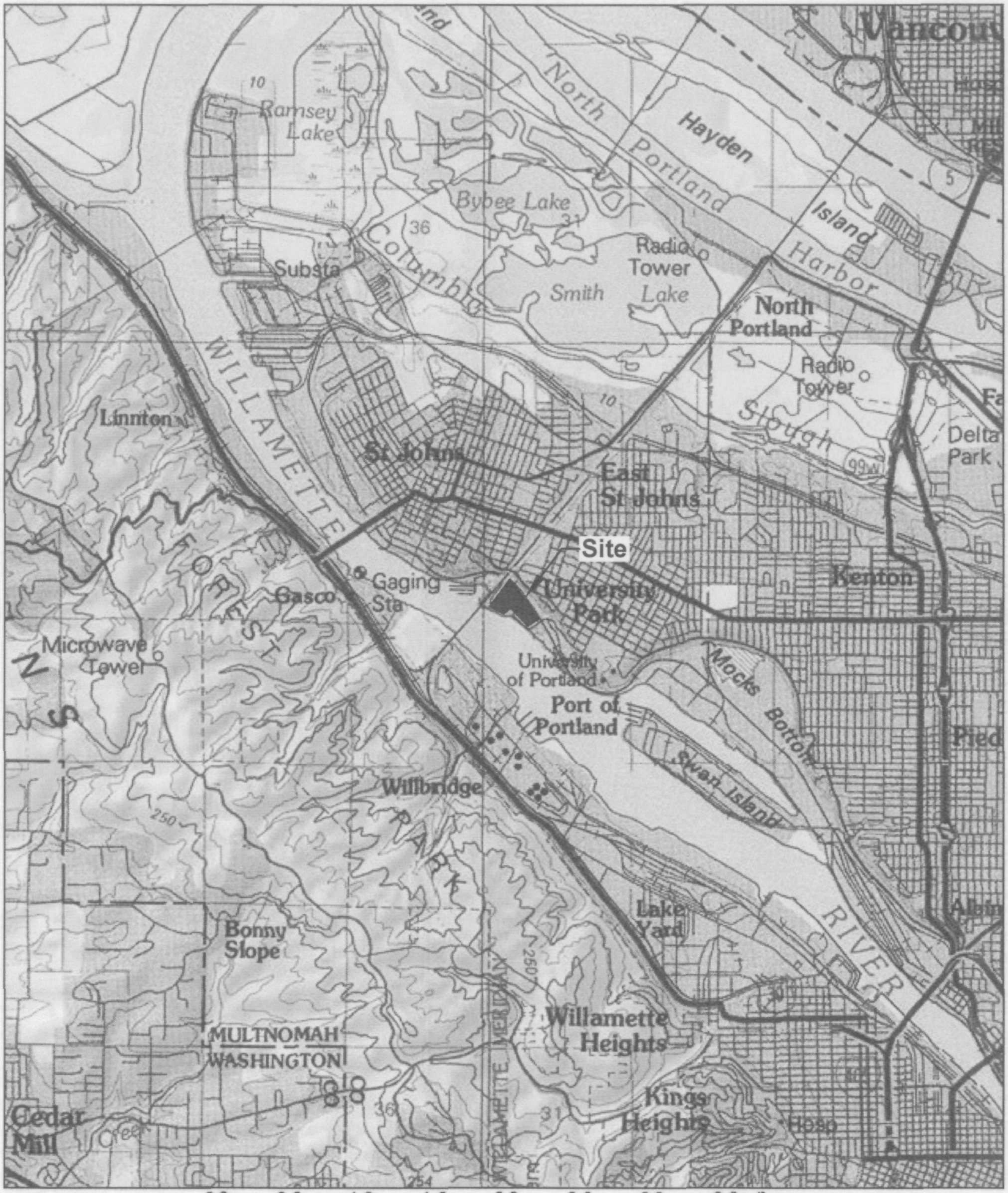
Alternative by Focus Area	NAPL[3] Recovery Efficiency (%)			NAPL Discharge Rate (ft^3/day)			Expected Life of Organoclay Cap (Yr)			Depletion Time for Mobile NAPL (Yr)			Cost			Cost/gallon		
	Min	Max	Expected	Min	Max	Expected	Min	Max	Expected	Min	Max	Expected	Low	High	Expected	Low	High	Expected
FWDA[1] to Willamette Cove - Flow Path 1																		
1 Current Condition Without Extraction	--	--	--	--	--	0.0075	--	--	515	--	--	130	$6,000	$125,000	$0	NA	NA	NA
2 Current Condition With Single phase extraction	1%	9.0%	5%	0.0066	0.0014	0.0035	590	2755	1115	20.5	0	0	$1,129,663	$2,658,030	$1,329,015	$110	$110	$110
3 Cold Water Flood	22%	65%	39%	0	0	0	infinite	infinite	infinite	0	0	0	$558,000	$8,140,000	$2,920,000	$85	$418	$250
4 Hot Water Flood	42%	83%	52%	0	0	0	infinite	infinite	infinite	0	0	0	$629,000	$12,700,000	$4,180,000	$49	$516	$263
5 In situ Chemical Oxidation	50%	99.9%	90%	0	0	0	infinite	infinite	infinite	0	0	0	$302,000	$6,550,000	$2,910,000	$20	$218	$108
6 Electrical Resistive Heating	90%	99.9%	99%	0	0	0	infinite	infinite	infinite	0	0	0	$753,000	$14,400,000	$12,300,000	$25	$480	$411
TFA[2] to Willamette River - Flow Path 6																		
1 Current condition Without Extraction	--	--	--	--	--	1.99	--	--	7.3	--	--	5.3	$6,000	$125,500	$0	NA	NA	NA
2 Single-phase extraction	1%	9.0%	5%	1.5	1	1.25	9.9	14.1	11.7	6	6.8	6.3	$411,636	$1,097,697	$508,492	$135	$135	$135
3 Cold Water Flood	22%	65%	39%	0.95	0	0.36	15.4	infinite	40.3	7	0	10	$558,000	$6,320,000	$2,330,000	$43	$165	$101
4 Hot Water Flood	42%	83%	52%	0.28	0.00	0.07	52	infinite	200	11	0	18.3	$629,000	$9,830,000	$3,340,000	$25	$203	$107
5 In situ Chemical Oxidation	50%	99.9%	90%	0.11	0	0	137	infinite	infinite	16	0	0	$302,000	$6,720,000	$1,450,000	$20	$114	$27
6 Electrical Resistive Heating	90%	99.9%	99%	0	0	0	infinite	infinite	infinite	0	0	0	$753,000	$14,400,000	$6,680,000	$13	$244	$113

Treatment Technologies
1 = Current Condition Without Extraction (No Action between barrier wall and shore line)
2 = Current Condition With Single-Phase Extraction
3 = Cold Water Flooding (CWF)
4 = Hot Water Flooding (HWF)
5 = In Situ Chemical Oxidation (ISCO)
6 = Electrical Resistive Heating (ERH)

Notes:
[1] FWDA - Former Waste Disposal Area
[2] TFA - Tank Farm Area
[3] NAPL - Non Aqueous Phase Liquid
NA = Not applicable

See Appendix B for back-up calculations

Notes:
Alternative 2 duration was based on depletion time for remaining NAPL (YR).
Annual costs from Tables B-3 and B-4 actual costs.
Capital costs for second and higher unit cells for innovative technologies were reduced by 35 percent to avoid redundant addition of costs for design and permitting



Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Aquifer Solutions, Inc. www.aquifersolutions.com	Vicinity Map	
	McCormick and Baxter Innovative Technology Evaluation Portland, Oregon	
AND GEOENGINEERS		Figure 1

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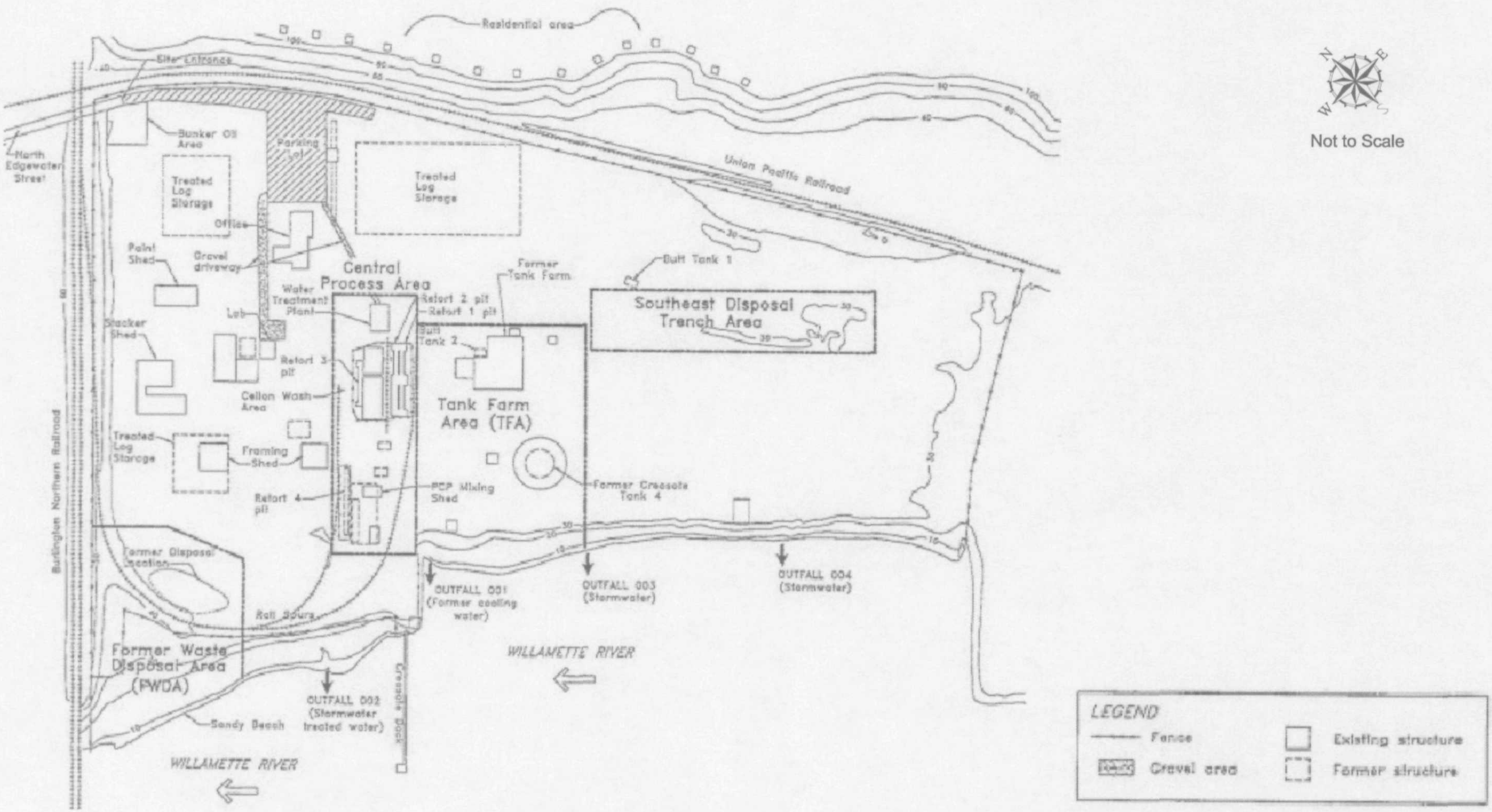

Historical Site Features Map

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

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Figure 2

Reference: Base drawing provided by Ecology and Environment, Inc., dated 3/23/05.

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Aerial photo dated July 31, 2005, and AutoCAD file entitled "Uplandcap_final.dwg", provided by Ecology and Environment, Inc., dated 02/25/05.

Aquifer Solutions, Inc. www.aquifersolutions.com	**Current Site Features** McCormick and Baxter Innovative Technology Evaluation Portland, Oregon	
AND GEOENGINEERS		**Figure 3**

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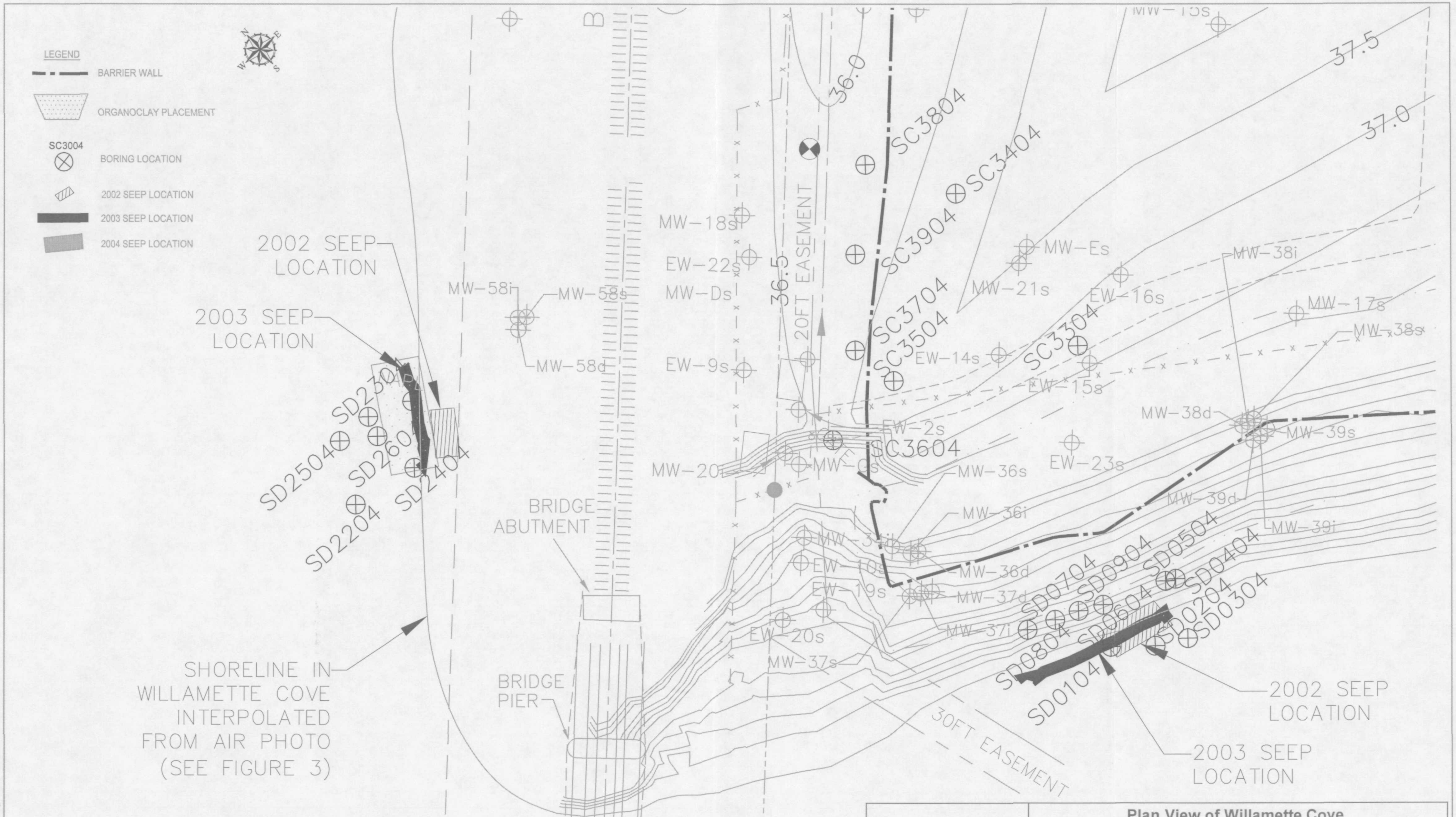

09/19/05
P:\2787018\00\Figure4.dwg EH2:MWJ

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. Water sample collected from boring location SD2304A.

Reference: Base drawing was an AutoCAD file entitled "FWDA 2004 Sample Location and Organoclay Placement Map", provided by Ecology and Environment, Inc., dated 02/25/05.

SCALE IN FEET
0 100 200

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Plan View of Willamette Cove
ITE Focus Area

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

Figure 4

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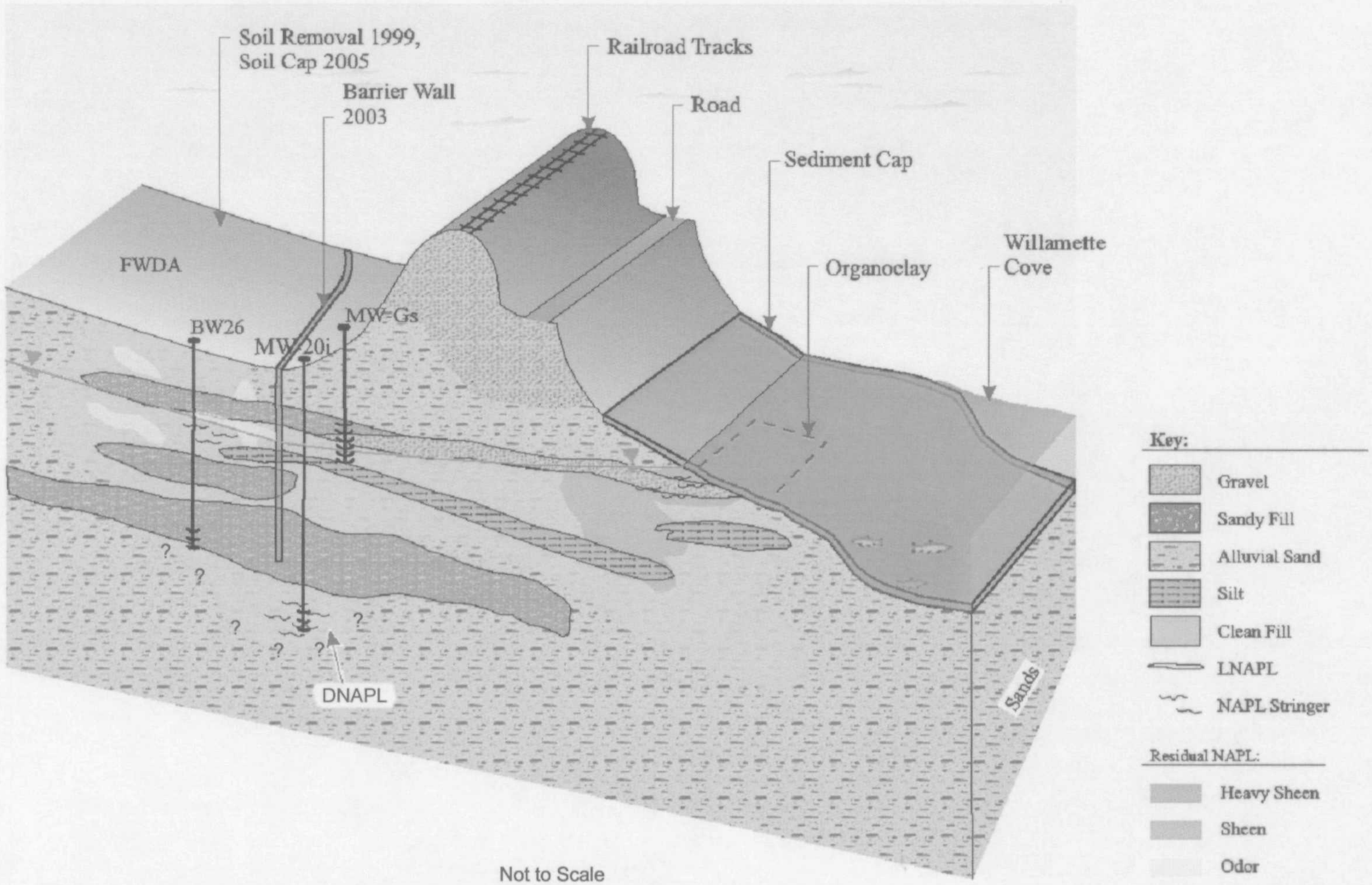

Not to Scale

Reference: Base drawing provided by Ecology and Environment, Inc., dated 3/23/05.

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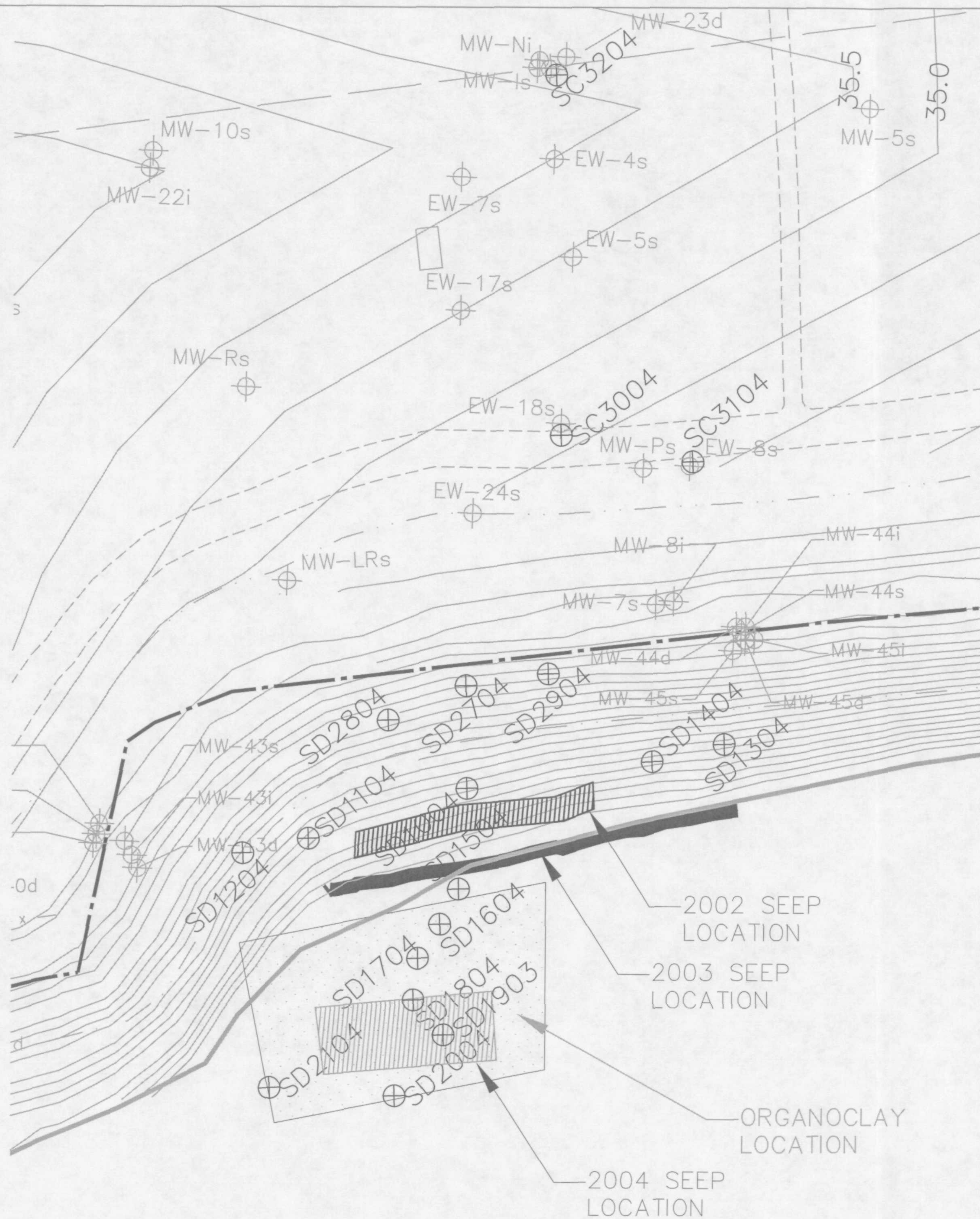
Willamette Cove Conceptual Site Model

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

Figure 5



LEGEND

BARRIER WALL

ORGANOCLAY PLACEMENT

SC3004 BORING LOCATION

2002 SEEP LOCATION

2003 SEEP LOCATION

2004 SEEP LOCATION

SCALE IN FEET

0 100 200 300

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. Water sample collected from boring location SD1004.

Reference: Base drawing was an AutoCAD file entitled "FWDA 2004 Sample Location and Organoclay Placement Map", provided by Ecology and Environment, Inc., dated 06/20/05.

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Tank Farm Area ITE Focus Area

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

Figure 6

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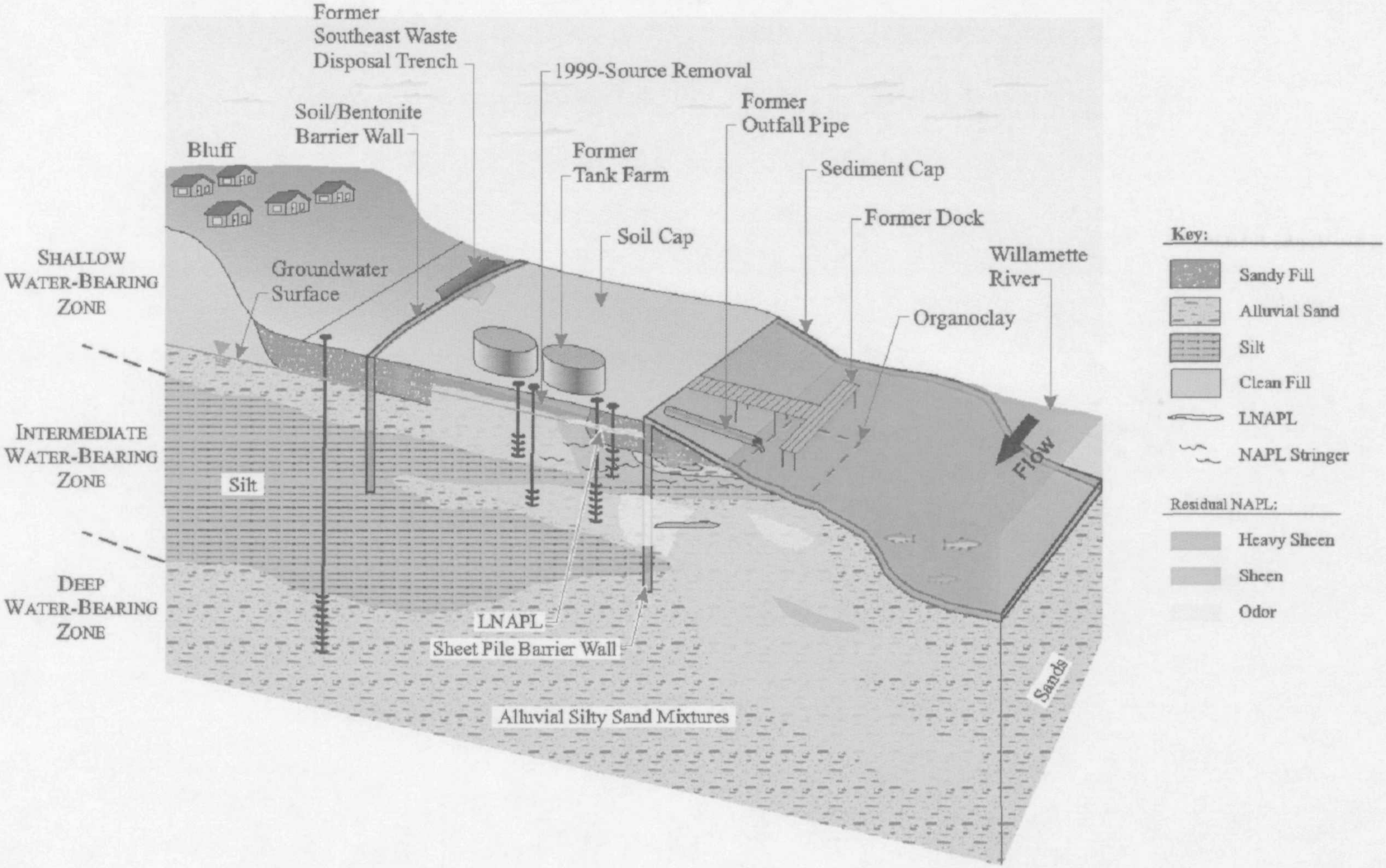

Reference: Base drawing provided by Ecology and Environment, Inc., dated 3/29/05.

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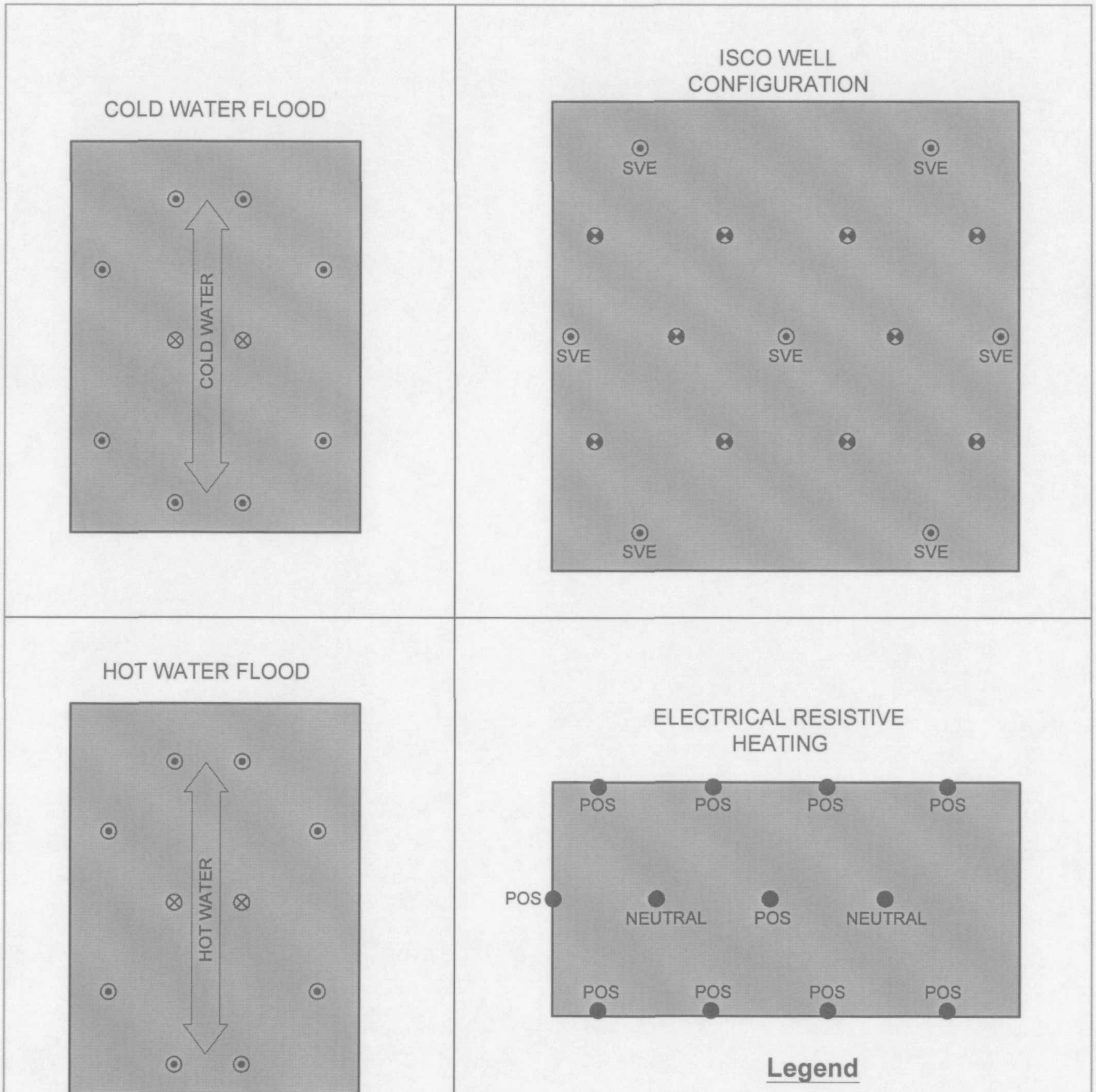
TFA Conceptual Site Model Schematic

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

Figure 7



Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Legend

- ISCO WELL
- INJECTION WELL
- EXTRACTION WELL
- ELECTRODE/EXTRACTION LOCATION

40 0 40
Approximate Scale in Feet

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Unit Cell Configuration Schematic

McCormick and Baxter Innovative Technology Evaluation
Portland, Oregon

AND GEOENGINEERS

Figure 8

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GeoEngineers

Appendix A
Calculation Sheets for Detailed Feasibility Evaluation

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:
(ROI: Radius of Influence)

Assumptions: Steady-state conditions, radial flow in an unconfined aquifer, neglect natural gradient (0.0038 ft/ft from TFA to FWDA)

Theim equation for steady-state radial flow in unconfined aquifer:

$$Q = (2(\pi)rh)K\ (dh/dr)$$ (Fetter, Applied Hydrogeology)

where,

Q = pumping rate
r = radial distance from the well
h = saturated thickness of aquifer
K = hydraulic conductivity
dh/dr = gradient

Parameters for McCromick & Baxter Site:

Q = Assume a 'Q' based on possible rates - Ranges from 40 gpm to 90 gpm
r = Assume a series of radii from 1 to 50 feet from the well
h = Saturated thickness - CSM geology section
FWDA: h = 26 ft
TFA: h = 16 ft
K = From Table A-12 for NAPL Mobility Study
FWDA to Willamette Cove: K = 80 ft/d
TFA: K = 60 ft/d
dh/dr = *The point at which the calculated gradient is just less than the total gradient required to mobilize NAPL determines the greatest extent of ROI*

From Table A-12 for NAPL Mobility Study

Critical oil gradient ft oil/ft:	FWDA:	0.0112	TFA:	0.0862
Total gradient in ft oil/ft:	FWDA:	0.0607	TFA:	0.1072
Oil density (g/cc):	FWDA:	1.015	TFA:	1.0952
Water density (g/cc):	FWDA:	1.0036	TFA:	1.0008

Total gradient in ft water/ft:

$$Grad_{total}\ (ft\ water/ft) = Grad_{total}\ (ft\ oil/ft) \times density_{oil}/density_{water}$$

Total Gradient in ft water/ft

FWDA: 0.061 TFA: 0.117

The distance where the calculated gradient is equal to or less than the total gradient = ROI

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Based on the critical gradient required to mobilize NAPL and site specific parameters for each area provided in the NAPL mobility study and CSM report, the following radii of influence were determined for the specified pumping rates:

FWDA: ROI ranges from 5.3 ft to 21.7 ft
Area of influence ranges from 88.25 ft^2 to 1479 ft^2
Volume of influence ranges from 2294.431 ft^3 to 38462.96 ft^3

Flow Rate (gpm)	ROI (ft)
22*	5.3
40	9.6
50	12.0
60	14.4
70	16.9
80	19.3
90	21.7

TFA: ROI ranges from 6 ft to 24.5 ft
Area of influence ranges from 113.1 ft^2 to 1886 ft^2
Volume of influence ranges from 1809.557 ft^3 to 30171.86 ft^3

Flow Rate (gpm)	ROI (ft)
22	6.0
40	10.9
50	13.6
60	16.3
70	19.0
80	21.8
90	24.5

Note:

These calculations are based on the simplified model of a single pumping well could achieve this radius of influence under steady state conditions. For simplicity reasons, no boundary condition influences or influences from superposition of wells are considered at this time. For a preliminary comparative analysis of technologies, it is assumed that an injection well in the same location will also be able to achieve a similar radius of influence.

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:
(continued - page 5)

K = From Table A-12 for NAPL Mobility Study
FWDA to Willamette Cove: K = 80 ft/d
TFA: K = 60 ft/d

dh/dr = *using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)*
FWDA = 0.061 ft/ft TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---> Q = 22 gpm = 4235 ft^3/d

FWDA:

r	dh/dr	refined r	refined dh/dr	
1	0.3240			
5	0.0648	5	0.0648	
10	0.0324	5.1	0.0635	ROI = 5.3 ft
15	0.0216	5.2	0.0623	
20	0.0162	5.3	0.0611	
25	0.0130	5.4	0.0600	
30	0.0108	5.5	0.0589	
35	0.0093			
40	0.0081			
45	0.0072			
50	0.0065			

Low pump rate calculation: Using eq. Above ---> Q = 22 gpm = 4235 ft^3/d

TFA:

r	dh/dr	refined r	refined dh/dr	
1	0.7021			
5	0.1404	5	0.1404	
10	0.0702	5.5	0.1277	ROI = 6.0 ft
15	0.0468	5.8	0.1211	
20	0.0351	5.9	0.1190	
25	0.0281	6	0.1170	
30	0.0234	6.1	0.1151	
35	0.0201			
40	0.0176			
45	0.0156			
50	0.0140			

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:
(continued - page 5)

K = From Table A-12 for NAPL Mobility Study
FWDA to Willamette Cove: K = 80 ft/d
TFA: K = 60 ft/d

dh/dr = using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)
FWDA = 0.061 ft/ft TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ----> Q = 40 gpm = 7700 ft^3/d

FWDA:

r	dh/dr
1	0.5892
5	0.1178
10	0.0589
15	0.0393
20	0.0295
25	0.0236
30	0.0196
35	0.0168
40	0.0147
45	0.0131
50	0.0118

refined

r	dh/dr
6	0.0982
8	0.0736
9	0.0655
9.5	0.0620
9.6	0.0614
9.7	0.0607

ROI = 9.6 ft

Low pump rate calculation: Using eq. Above ----> Q = 40 gpm = 7700 ft^3/d

TFA:

r	dh/dr
1	1.2766
5	0.2553
10	0.1277
15	0.0851
20	0.0638
25	0.0511
30	0.0426
35	0.0365
40	0.0319
45	0.0284
50	0.0255

refined

r	dh/dr
10	0.1277
10.6	0.1204
10.7	0.1193
10.8	0.1182
10.9	0.1171
11	0.1161

ROI = 10.9 ft

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:
(continued - page 5)

K = From Table A-12 for NAPL Mobility Study
FWDA to Willamette Cove: K = 80 ft/d
TFA: K = 60 ft/d

dh/dr = using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)
FWDA = 0.061 ft/ft TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---> Q = 50 gpm = 9625 ft^3/d

FWDA:

r	dh/dr
1	0.7365
5	0.1473
10	0.0736
15	0.0491
20	0.0368
25	0.0295
30	0.0245
35	0.0210
40	0.0184
45	0.0164
50	0.0147

refined

r	dh/dr
10	0.0736
11	0.0670
11.8	0.0624
11.9	0.0619
12	0.0614
12.1	0.0609

ROI = 12.0 ft

Low pump rate calculation: Using eq. Above ---> Q = 50 gpm = 9625 ft^3/d

TFA:

r	dh/dr
1	1.5957
5	0.3191
10	0.1596
15	0.1064
20	0.0798
25	0.0638
30	0.0532
35	0.0456
40	0.0399
45	0.0355
50	0.0319

refined

r	dh/dr
13	0.1227
13.5	0.1182
13.6	0.1173
13.7	0.1165
13.8	0.1156
13.9	0.1148

ROI = 13.6 ft

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:
Date:

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:

(continued - page 5)

K = From Table A-12 for NAPL Mobility Study

FWDA to Willamette Cove: K = 80 ft/d

TFA: K = 60 ft/d

dh/dr = using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)

FWDA = 0.061 ft/ft   TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---> Q = 60 gpm = 11550 ft^3/d

FWDA:

r	dh/dr		refined r	refined dh/dr	
1	0.8838		12	0.0736	
5	0.1768		13	0.0680	ROI = 14.4 ft
10	0.0884		14	0.0631	
15	0.0589		14.3	0.0618	
20	0.0442		14.4	0.0614	
25	0.0354		14.5	0.0609	
30	0.0295				
35	0.0253				
40	0.0221				
45	0.0196				
50	0.0177				

Low pump rate calculation: Using eq. Above ---> Q = 60 gpm = 11550 ft^3/d

TFA:

r	dh/dr		refined r	refined dh/dr	
1	1.9148		15	0.1277	
5	0.3830		16	0.1197	ROI = 16.3 ft
10	0.1915		16.2	0.1182	
15	0.1277		16.3	0.1175	
20	0.0957		16.4	0.1168	
25	0.0766		16.5	0.1161	
30	0.0638				
35	0.0547				
40	0.0479				
45	0.0426				
50	0.0383				

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:
(continued - page 5)

K = From Table A-12 for NAPL Mobility Study
FWDA to Willamette Cove: K = 80 ft/d
TFA: K = 60 ft/d

dh/dr = using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)
FWDA = 0.061 ft/ft   TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---->   Q = 70 gpm = 13475 ft^3/d

FWDA:

r	dh/dr
1	1.0311
5	0.2062
10	0.1031
15	0.0687
20	0.0516
25	0.0412
30	0.0344
35	0.0295
40	0.0258
45	0.0229
50	0.0206

refined

r	dh/dr
15	0.0687
16	0.0644
16.5	0.0625
16.8	0.0614
16.9	0.0610
17	0.0607

ROI = 16.9 ft

Low pump rate calculation: Using eq. Above ---->   Q = 70 gpm = 13475 ft^3/d

TFA:

r	dh/dr
1	2.2340
5	0.4468
10	0.2234
15	0.1489
20	0.1117
25	0.0894
30	0.0745
35	0.0638
40	0.0558
45	0.0496
50	0.0447

refined

r	dh/dr
18	0.1241
18.5	0.1208
19	0.1176
19.1	0.1170
19.2	0.1164
19.3	0.1157

ROI = 19 ft

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:__________
Date:__________

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:

(continued - page 5)

K = From Table A-12 for NAPL Mobility Study

FWDA to Willamette Cove: K = 80 ft/d

TFA: K = 60 ft/d

dh/dr = using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)

FWDA = 0.061 ft/ft TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---> Q = 80 gpm = 15400 ft^3/d

FWDA:

r	dh/dr
1	1.1784
5	0.2357
10	0.1178
15	0.0786
20	0.0589
25	0.0471
30	0.0393
35	0.0337
40	0.0295
45	0.0262
50	0.0236

refined

r	dh/dr
16	0.0736
18	0.0655
19	0.0620
19.2	0.0614
19.3	0.0611
19.4	0.0607

ROI = 19.3 ft

Low pump rate calculation: Using eq. Above ---> Q = 80 gpm = 15400 ft^3/d

TFA:

r	dh/dr
1	2.5531
5	0.5106
10	0.2553
15	0.1702
20	0.1277
25	0.1021
30	0.0851
35	0.0729
40	0.0638
45	0.0567
50	0.0511

refined

r	dh/dr
21	0.1216
21.5	0.1187
21.6	0.1182
21.7	0.1177
21.8	0.1171
21.9	0.1166

ROI = 21.8 ft

Project Name: McCorm & Bax (GeoEngineers and ODEQ)
Project Number: 1047
Calc. By: SJS
Date: 5/30/05

Checked By:
Date:

Calculation Sheet

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Calculation of Gradient (dh/dr) at specified distances (ROIs) from a single pumping well:

(continued - page 5)

K = From Table A-12 for NAPL Mobility Study

FWDA to Willamette Cove: K = 80 ft/d

TFA: K = 60 ft/d

dh/dr = *using the total gradient required to achieve the critical gradient of oil flow (any lesser gradient would not be recovering NAPL)*

FWDA = 0.061 ft/ft TFA = 0.117 ft/ft

Low pump rate calculation: Using eq. Above ---> Q = 90 gpm = 17325 ft^3/d

FWDA:

r	dh/dr	refined r	refined dh/dr
1	1.3257		
5	0.2651	21	0.0631
10	0.1326	21.5	0.0617
15	0.0884	21.6	0.0614
20	0.0663	21.7	0.0611
25	0.0530	21.8	0.0608
30	0.0442	21.9	0.0605
35	0.0379		
40	0.0331		
45	0.0295		
50	0.0265		

ROI = 21.7 ft

Low pump rate calculation: Using eq. Above ---> Q = 90 gpm = 17325 ft^3/d

TFA:

r	dh/dr	refined r	refined dh/dr
1	2.8722		
5	0.5744	22	0.1306
10	0.2872	23	0.1249
15	0.1915	24	0.1197
20	0.1436	24.5	0.1172
25	0.1149	24.6	0.1168
30	0.0957	24.7	0.1163
35	0.0821		
40	0.0718		
45	0.0638		
50	0.0574		

ROI = 24.5 ft

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
Date: 5/20/05

Checked By: BKM
Date: 09/19/05

Calculation Sheet

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Calculation of energy needed to heat one unit of saturated soil:
Data from Thermal Conductivity Science (www.hukseflux.com/thermal%20conductivity/thermal.html):

	Thermal conductivity @20° C W/mK	Density @20° C Kg/m^3	Volumetric heat capacity @20° C 10^6 J/m^3	Thermal diffusivity @20° C 10^{-8} m^2/s
Air	0.025	1.29	0.001	1938
Water	0.6	1000	4.180	14
Sand (dry)	0.35	1600	1.270	28
Sand (saturated)	2.7	2100	2.640	102

A list of typical values of thermal properties of various materials.

Range of all reported values for soil	0.15 to 4
Saturated soil	0.6 to 4
Sand perfectly dry	0.15 to 0.25
Sand moist	0.25 to 2
Sand saturated	2 to 4
Clay dry to moist	0.15 to 1.8
Clay saturated	0.6 to 2.5
Soil with organic matter	0.15 to 2

Table 8.6.2 *Reported values, as known to the author, of thermal conductivity in different soil types in W/mK.*

Calculations:

Using the volumetric heat capacity of "sand (saturated)" from the first table.

Volumetric heat capacity = amount of heat energy per unit volume to raise temperature of one cubic meter of substance 1°C = c_v

$c_{v(\text{saturated sand})} = 2.640E6$ J/m^3 2.64E+06

Convert to Kilowatt-hours: 2.64E+06 J/m3 = 7.33E-01 KWH/m3

Conversion factor: 1 J = 2.78E-07 KWH

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
Date: 5/20/05

Checked By: BKM
Date: 09/19/05

Calculation Sheet

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Unit Cell Dimensions

FWDA:	100ft x 75ft x 26ft	195000	cf	=	5521.776	m3
TFA:	125ft x 80ft x 16ft	160000	cf	=	4530.688	m3

Goal temperature: 175 °F or 79.44 °C

Based on maximum temperature for minimum viscosity for NAPL product.

Background temperature: 59 °F or 15 °C From CMS report (temp/viscos. Chart)

Change in temperature required: 64 °C = ΔC

To raise 1 °C

$C_{v(\text{saturated sand})} = 2.640E6 \text{ J/m}^3$ or 7.33E-01 KWH/m3

To raise 64 °C

$C_{v(\text{saturated sand})} =$ 7.33E-01 x 64 = 4.69E+01 KWH/m3

For one unit cell the total energy needed would be:

$Total_{energy} = C_{v(\Delta 64oC)}$ x volume

FWDA:	$Total_{energy}$ =	4.69E+01 KWH/m3 x	5521.776 m3	=	2.59E+05	KWH
TFA:	$Total_{energy}$ =	4.69E+01 KWH/m3 x	4530.688 m3	=	2.13E+05	KWH

FWDA:	8.83E+08 Btu
TFA:	7.25E+08 Btu

Boiler Output $Total_{energy}$ / Duration (hours)

	Min	Max	Expected	
Duration:	12	48	36	months
Duration:	8784	35136	26352	hours

Boiler Output (Btu/hr)

	Min	Max	Expected	Average
FWDA:	100,560	25,140	33,520	
TFA:	82,511	20,628	27,504	30,512

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
Date: 5/20/05

Checked By: BKM
Date: 09/19/05

Calculation Sheet

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Boiler Output Total_{energy} / Duration (hours)

	Min	Max	Expected	
Duration:	12	48	36	months
Duration:	8784	35136	26352	hours

Boiler Output (Btu/hr)

	Min	Max	Expected	Average
FWDA:	1.01E+05	25,140	33,520	
TFA:	82,511	20,628	27,504	30,512

Account for boiler efficiency of 85%	35088.53
Account for loses to soil gas and other in situ losses at 35%	47369.51

Calculation of natural gas requirement for hot water flooding:

Average Boiler Output Requirement from previous page: 30,512 Btu/HR

Thermal capacity of natural gas (http://hypertextbook.com/facts/2002/JanyTran.shtml)

"Fuel Gas." *McGraw Hill Encyclopedia of Science & Technology*. McGraw Hill, Inc., 1982.

"The net heating value of natural gas served by a utility company is often 1000 to 1100 Btu/ft3."

use 1000 Btu/cubic foot of natural gas

47,370	Btu/HR	=	47	Cubic foot/HR
1000	BTU/Cubic foot			
		=	1137	Cubic feet/Day

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
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Date: 09/19/05

Calculation Sheet

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Calculation of energy needed to heat one unit of saturated soil (continued):

Electrical Resistive Heating calculations:

Unit Cell Dimensions

FWDA:	40ft x 40ft x 26ft	41600	cf	=	1177.97888	cm
TFA:	40ft x 40ft x 16ft	25600	cf	=	724.91008	cm

Goal temperature: 212 °F or 100 °C

Based on maximum temperature for minimum viscosity for NAPL product.

Background temperature: 59 °F or 15 °C From CMS report (temp/viscos. Chart)

Change in temperature required: 85 °C = ΔC

To raise 1 °C

$C_{v(\text{saturated sand})} = 2.640E6\ J/m^3$ or 7.33E-01 KWH/m3

To raise 85 °C

$C_{v(\text{saturated sand})} =$ 7.33E-01 x 85 = 6.23E+01 KWH/m3

For one unit cell the initial energy needed would be:

$Total_{energy} = C_{v(\Delta 85oC)} \times volume$

FWDA:	$Total_{energy}$ =	6.23E+01 KWH/m3 x	1177.979	m3	=	7.34E+04	KWH
TFA:	$Total_{energy}$ =	6.23E+01 KWH/m3 x	724.9101	m3	=	4.52E+04	KWH

Additional heat is required to maintain temperature as compared to initial heating:

Maintenance Factor: 5 Unitless

FWDA:	=	3.67E+05 KWH
TFA:	=	2.26E+05 KWH

Total heat requirement by area:

FWDA:	=	4.40E+05 KWH
TFA:	=	2.71E+05 KWH

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
Date: 5/20/05

Checked By: BKM
Date: 09/19/05

Calculation Sheet

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Calculation of electrical energy needed for each treatment deployment scenario:

Calculations for Unit Processes for Flooding and ERH Electrical Energy Required

Process	Unit	Voltage	Amps	Phase	% Usage	Total Watts	KW
AOP/Ozone	Integrated system	480	20	3	0.8	7680	7.68
	Chemical pump (peroxide)	115	17	1	0.8	1564	1.564
	Transfer pump	480	21	3	1	10080	10.08
	Misc pump (sump)	115	17	1	0.1	195.5	0.1955
Granular Filters	Filter pump	480	30	3	0.1	1440	1.44
	Agitator	480	10	3	0.1	480	0.48
	Compressor	115	30	1	0.2	690	0.69
	Panel	115	30	1	1	3450	3.45
Controls	Controls System and Trailer	115	80	1	1	9200	9.2
Misc	outlets (6)	115	120	1	0.02	276	0.276
Misc	lighting	115	20	1	0.02	46	0.046
Heat/Vent	Misc heating/venting fans	115	5	1	0.3	172.5	0.1725
Boiler	Boilers (2)	115	20	1	0.4	920	0.92
	Boiler recirc pump	480	30	3	0.2	2880	2.88
SVE	blower - high flow	230	26	3	1	5980	5.98
	blower - low flow	230	22	3	1	5060	5.06
	transfer pumps	230	4	1	0.25	230	0.23
	fans	230	20	1	1	4600	4.6

Technology	Treatment Unit Processes	Total Watts	KW
Cold Water Flooding	pumps, filter, controls, misc	26030	26.03
Hot Water Flooding	pumps, filter, AOP/ozone, controls, misc, heat/vent, boiler	39074	39.074
ERH	pump, filter, AOP/ozone, controls, misc, heat/vent, SVE	51144	51.144

Calculations for ISCO Electrical Energy Required

Process	Unit	Voltage	Amps	Phase	% Usage	Total Watts	KW
Ozone	Air compressor	480	40	3	0.5	9600	9.6
	Chiller	480	23	3	0.5	5520	5.52
	Ozone generator 1	480	15	3	1	7200	7.2
	Ozone generator 2	480	15	3	1	7200	7.2
Air supply/monitoring	Air reciever auto drain	115	0.25	1	1	28.75	0.02875
	Air dryer	115	1	1	1	115	0.115
	SVE ozone monitor	115	3	1	1	345	0.345
	Ambient ozone monitor	115	4	1	1	460	0.46
	Dew point meter	115	1	1	1	115	0.115
	Ozone process meter	115	1	1	1	115	0.115
Control	PLC	120	0.2	1	1	24	0.024
SVE	Blower - high flow	230	26	3	1	5980	5.98
	Blower - low flow	230	22	3	1	5060	5.06
	Transfer pumps	230	4	1	0.25	230	0.23
	Fans	230	20	1	1	4600	4.6
Misc	Outlets	115	40	1	0.02	92	0.092
Misc	Lighting	115	20	1	0.02	46	0.046
					Total	46730.75	46.73075

Project Name: McCormick and Baxter
Project Number: 1047
Calc. By: SJS
Date: 5/20/05

Checked By: BKM
Date: 09/19/05

Calculation Sheet

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Calculation of electrical energy needed for each treatment deployment scenario (cont.):

Once the total kilowatts (KW) are determined for a technology, the total electrical energy for the duration of the operation of the treatment system can be calculated.

Example Calculation for Hot Water Flooding:

Total energy required for treatment unit processes:	Expected		26	KW
Total hours of operation (expected from Table 3):	48 months	≈	35136	hours

For the total electrical energy required for the above ground treatment unit processes
Multiply the KW * time to get KWhr: 913536 KWH

For ERH, additional calculations apply
Add the energy required to heat the subsurface (See thermal calc sheet):

Electrical $Energy_{TreatmentProcesses}$	=	913536	KWH	
$Energy_{ThermalHeatRequirements}$	=	259000	KWH	for FWDA
	=	213000	KWH	for TFA
Ave(thermal energy)	=	236000	KWH	

Total energy required for ERH ≈ 1149536 KWH or 1.1E+06 KWH

GeoEngineers

Appendix B
NAPL Mobility

TABLE B-1
HYPOTHETICAL SEEP REPAIR COST SUMMARY
OC BLANKET REPAIR
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

Element	Unit Rate	Quantity	Units	Capital Cost
Mobilization/Demobilization/Submittals	$ 2,000	1	lump	$ 2,000
Surveying	$ 500	1	lump	$ 500
Materials (Purchase, Deliver and Place):				
Organoclay	$ 1.60	450	sq ft	$ 720
Sand overlayment	$ 7.38	22	tons	$ 162
Filtergravel	$ 17.80	7	tons	$ 125
10-inch minus rock armoring	$ 25.06	22	tons	$ 551
Capital Cost Subtotal				$ 4,058
Direct Capital Cost				
Total Construction Cost				$ 4,058
Construction Contingency (30%)				$ 1,217
Total Direct Capital Cost				$ 5,276
Indirect Capital Cost				
Construction Oversight (10%)				$ 406
Project Management (10%)				$ 122
Total Indirect Capital Cost				$ 528
TOTAL CAPITAL COST				**$ 5,803**

Notes and Assumptions:
Cost estimate does not include design and permiting
Construction is done mostly in the dry or very shallow water with land-based equipment
Repair Area = 225 SF
Material thicknesses:
Organoclay = 15' x15' blanket
Sand overlayment = 1 foot
Filtergravel = 1/3 foot
10-inch minus rock armoring = 1.0 feet
Density of sand and rock = 1.5 tons/CY
Density of organoclay = 50 lbs/CF = 0.675 tons/CY
Material quantities:
Organoclay = 2 blankets
Sand overlayment = 400 CF foot / 27 CF per CY * 1.5 tons/CY = 22 tons
Filtergravel = 120 CF / 27 CF per CY * 1.5 tons/CY = 7 tons
10-inch minus rock armoring = 400 CY / 27 CF per CY * 1.5 tons/CY = 22 tons
Unit cost of materials based on contract unit quanities for 2004 sediment cap construction:
Organoclay = $1.60/sq. ft.
Sand = $7.38/ton
Filter gravel = $17.80/ton
Rock armoring = $25.06/ton

TABLE B-2
HYPOTHETICAL SEEP REPAIR COST SUMMARY
OC LAYER REPAIR
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

Element	Unit Rate	Quantity	Units	Capital Cost
Mobilization/Demobilization/Submittals	$ 20,000	1	lump	$ 20,000
Surveying	$ 2,500	1	lump	$ 2,500
Materials (Purchase, Deliver and Place):				
Organoclay	$ 1.25	50,000	lbs	$ 62,500
Sand overlayment	$ 7.38	55	tons	$ 406
Filtergravel	$ 17.80	19	tons	$ 329
10-inch minus rock armoring	$ 25.06	83	tons	$ 2,080
Capital Cost Subtotal				$ 87,815
Direct Capital Cost				
Total Construction Cost				$ 87,815
Construction Contingency (30%)				$ 26,345
Total Direct Capital Cost				$ 114,160
Indirect Capital Cost				
Construction Oversight (10%)				$ 8,782
Project Management (10%)				$ 2,634
Total Indirect Capital Cost				$ 11,416
TOTAL CAPITAL COST				**$ 125,576**

Notes and Assumptions:
Cost estimate does not include design and permiting
Construction is done mostly in the dry or very shallow water with land-based equipment
Repair Area = 1,000 SF
Material thicknesses:
- Organoclay = 1 foot
- Sand overlayment = 1 foot
- Filtergravel = 1/3 foot
- 10-inch minus rock armoring = 1.5 feet

Density of sand and rock = 1.5 tons/CY
Density of organoclay = 50 lbs/CF = 0.675 tons/CY
Material quantities:
- Organoclay = 1,000 CF * 50 lbs per CF = 50,000 lbs
- Sand overlayment = 1,000 CF foot / 27 CF per CY * 1.5 tons/CY = 55 tons
- Filtergravel = 333 CF / 27 CF per CY * 1.5 tons/CY = 18.5 tons
- 10-inch minus rock armoring = 1,500 CY / 27 CF per CY * 1.5 tons/CY = 83.3 tons

Unit cost of materials based on contract unit quanities for 2004 sediment cap construction:
- Organoclay = $1.25/lb
- Sand = $7.38/ton
- Filter gravel = $17.80/ton
- Rock armoring = $25.06/ton

TABLE B-3
SINGLE-PHASE NAPL EXTRACTION COST SUMMARY - TFA
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

Element	Unit Rate	Quantity	Units	Capital Cost
Technician Labor (currently 16 hours per week).	$35	1,184	hour	$ 41,440
Well Installation and Development	$7,500	3	well	$ 22,500
Truck	$455	17	month	$ 7,735
Personal Protective Equipment (PPE) (includes sorbent pads, tubing, etc.)	$160	17	month	$ 2,720
Air Compressor	$65	74	week	$ 4,810
Misc.: Barrels, supplies	$100	17	month	$ 1,700
Cost Subtotal				$ 80,905
Disposal Costs				
NAPL Disposal	$1	878	gallons	$ 878
NAPL Transport	$1,920	1	lump	$ 1,920
PPE Disposal (includes cost of tote)	$315	8	tote	$ 2,520
Sub Total Disposal Cost				$ 5,318
Oversight Costs				
E & E Oversight (P-1 4 hours per week)	$67	296	hour	$ 19,832
E & E Project Management (P-3 1 hour per week)	$112	74	hour	$ 8,288
Sub Total Oversight Cost				$ 28,120
TOTAL COST				**$ 114,343**
Total NAPL (in gallons)	858			
Total Cost	$114,343			
Cost per gallon of NAPL	$133			
Cost per month	$6,726			

Notes and Assumptions:
Cost estimate based on data from January 2004 through June 8, 2005 (17 Months)
Total NAPL recovered was 878 gallons (total LNAPL extracted was 165 gallons; DNAPL 713 gallons).
Volumes are from wells outside the barrier wall.
Extraction wells include three new extraction wells added to provide a range of coverage.
Volumes are calculated based on visual observations (e.g. no. of buckets) from Jan. 2004 to August 2004
and from drum gauging data from September 2004 to June 2005.
Extraction is done manually using bailers (LNAPL) or pump (DNAPL).
Assumes a bulk disposal of NAPL during a single disposal event.
Equipment and labor rates based on current Munitor subcontract with E & E (March 2005).
Technician labor includes guaging, extraction, storage, volume est. and reporting.
E & E P-1 oversight includes communication with subcontractor, data review, site visits
Assumes air compressor rental at $65 per week.
PPE costs based on average cost per month.
Hours estimates are based on a total of 74 weeks between February 2004 and June 2005.

TABLE B-4
SINGLE-PHASE NAPL EXTRACTION COST SUMMARY - FWDA
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

Element	Unit Rate	Quantity	Units	Capital Cost
Technician Labor (currently 16 hours per week).	$35	1,184	hour	$ 41,440
Truck	$455	17	month	$ 7,735
Personal Protective Equipment (PPE) (includes sorbent pads, tubing, etc.)	$160	17	month	$ 2,720
Air Compressor	$65	74	week	$ 4,810
Misc.: Barrels, supplies	$100	17	month	$ 1,700
Cost Subtotal				$ 58,405
Disposal Costs				
NAPL Disposal	$1	878	gallons	$ 878
NAPL Transport	$1,920	1	lump	$ 1,920
PPE Disposal (includes cost of tote)	$315	8	tote	$ 2,520
Sub Total Disposal Cost				$ 5,318
Oversight Costs				
E & E Oversight (P-1 4 hours per week)	$67	296	hour	$ 19,832
E & E Project Management (P-3 1 hour per week)	$112	74	hour	$ 8,288
Sub Total Oversight Cost				$ 28,120
TOTAL COST				**$ 91,843**
Total NAPL (in gallons)	858			
Total Cost	$91,843			
Cost per gallon of NAPL	$107			
Cost per month	$5,403			

Notes and Assumptions:

Cost estimate based on data from January 2004 through June 8, 2005 (17 Months).
Total NAPL recovered was 878 gallons (total LNAPL extracted was 165 gallons, DNAPL 713 gallons).
Volumes are from wells outside the barrier wall.
Extraction wells include: MW-20i, MW-Ds, MW-Gs, EW-2s, EW-9s, EW-10s.
Volumes are calculated based on visual observations (e.g. no. of buckets) from Jan. 2004 to August 2004 and from drum gauging data from September 2004 to June 2005.
Extraction is done manually using bailers (LNAPL) or pump (DNAPL).
Assumes a bulk disposal of NAPL during a single disposal event.
Equipment and labor rates based on current Munitor subcontract with E & E (March 2005).
Technician labor includes guaging, extraction, storage, volume est. and reporting.
E & E P-1 oversight includes communication with subcontractor, data review, site visits
Assumes air compressor rental at $65 per week.
PPE costs based on average cost per month.
Hours estimates are based on a total of 74 weeks between February 2004 and June 2005.

TABLE B-5

NAPL FLOW CALCULATIONS

INNOVATIVE TECHNOLOGY EVALUATION

McCORMICK AND BAXTER

PORTLAND, OREGON

input from Comp_Eval

Area					FWDA to Willamette Cove															
Flow path					1. Barrier Wall to Seep Area															
Direction					Horizontal															
Fluid					LNAPL															
Alternative by Focus Area					Cold Water Flood			Hot Water Flood			ISCO			ERH			Current Condition With Single-Phase Extraction			Current Condition w/o Extraction
NAPL recovery efficiency					0.22	0.65	0.39	0.42	0.83	0.52	0.50	0.999	0.90	0.90	0.999	0.99	0.01	0.090	0.05	
Variables / units	Input	Flow path data	L	ft	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320
			W	ft	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
			D	ft	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
			Ho	ft	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21
			Ho (mob)	ft	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259	2.259
			hw1	ft, NGVD	included in ho1															
			hw2	ft, NGVD	included in ho2															
			iw	ft water /ft																
			ho1	ft, NGVD	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88	7.88
			ho2	ft, NGVD	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
			hs1	ft, NGVD																
			hs2	ft, NGVD																
		Soil properties	Descr.		m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand	m-c sand
			Kwsat	ft/d	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
			n		0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402
			Srw		0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316
			Sro		**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**	**0.086**
			a	1/m	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07	17.07
			a	1/ft	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
			N		3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
			kroe		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			no		2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
		Fluid data	saw	dyne/cm	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0
			sao	dyne/cm	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.6
			sow	dyne/cm	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
			go	g/cc	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947
			gw	g/cc	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036	1.0036
			uo	cp	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31
			uw	cp	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969	1.0969
	Results		So (avg)																	0.060
			So (max)																	0.201
			So (mob)		**0.081**	**0.036**	**0.063**	**0.060**	**0.018**	**0.050**	**0.052**	**0.000**	**0.010**	**0.010**	**0.000**	**0.001**	**0.102**	**0.094**	**0.098**	**0.103**
			Son		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.014	0.021	0.029
			kro		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00037	0.00008	0.00019	0.00042
			Kosat	ft/d	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
			Ko	ft/d	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0017	0.0004	0.0009	0.0020
			bf		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			iw	ft water /ft	(included in io)															
			iw	ft oil/ft	(included in io)															
			io	ft oil/ft	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239
			is	ft/ft																
			it	ft oil/ft	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239	0.0239
			ic	ft oil/ft																
			Av	ft2	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12	158.12
			Ah	ft2																
			Ahs	ft2	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150
			Qo	ft3/d	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0066	0.0014	0.0035	0.0075
			Qo	gal/d	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.011	0.026	0.056
			Qo/Ah	gal/yr/ft2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0057	0.0012	0.0030	0.0065
			Qo direction		NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	SW	SW	SW	NW
			SC	dyne/cm	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Notes			1. Positive vertical gradients indicate upward flow direction. 1. Positive vertical gradients indicate upward flow direction.																	

TABLE B-5
NAPL FLOW CALCULATIONS
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK AND BAXTER
PORTLAND, OREGON

input from Comp_Eval

Area					TFA to Willamette River															
Flow path					6. Barrier wall to shoreline															
Direction					Horizontal															
Fluid					DNAPL															
Alternative by Focus Area					Cold Water Flood			Hot Water Flood			ISCO			ERH			Current Condition With Single-Phase Extraction			Current Condition Without Extraction
NAPL recovery efficiency					0.22	0.65	0.39	0.42	0.83	0.52	0.50	0.999	0.90	0.90	0.999	0.99	0.10	0.20	0.15	
Variables / units	Input	Flow path data	L	ft	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
			W	ft	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
			D	ft	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
			Ho	ft	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23
			Ho (mob)	ft	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21
			hw1	ft, NGVD																
			hw2	ft, NGVD																
			iw	ft water /ft	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			ho1	ft, NGVD	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03
			ho2	ft, NGVD	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30
			hs1	ft, NGVD	included in ho1															
			hs2	ft, NGVD	included in ho2															
		Soil properties	Descr.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Kwsat	ft/d	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
			n		0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406
			Srw		0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626	0.626
			Sro		**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**	**0.100**
			a	1/m	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
			a	1/ft	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23
			N		3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
			kroe		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			no		1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
		Fluid data	saw	dyne/cm	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30	70.30
			sao	dyne/cm	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35	34.35
			sow	dyne/cm	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94	17.94
			go	g/cc	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952
			gw	g/cc	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008	1.0008
			uo	cp	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31	24.31
			uw	cp	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760	1.0760
	Results		So (avg)																	0.230
			So (max)																	0.358
			So (mob)		**0.193**	**0.086**	**0.151**	**0.143**	**0.042**	**0.119**	**0.124**	**0.000**	**0.025**	**0.025**	**0.000**	**0.002**	**0.222**	**0.198**	**0.210**	**0.247**
			Son		0.339	0.000	0.185	0.158	0.000	0.068	0.086	0.000	0.000	0.000	0.000	0.000	0.447	0.357	0.402	0.537
			kro		0.17675	0.00000	0.06734	0.05230	0.00000	0.01354	0.01973	0.00000	0.00000	0.00000	0.00000	0.00000	0.27550	0.19206	0.23237	0.36974
			Kosat	ft/d	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91
			Ko	ft/d	0.5137	0.0000	0.1957	0.1520	0.0000	0.0393	0.0573	0.0000	0.0000	0.0000	0.0000	0.0000	0.8007	0.5582	0.6753	1.0746
			bf		0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862
			iw	ft water /ft																
			iw	ft oil/ft	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			io	ft oil/ft	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
			is	ft/ft	(included in io)															
			it	ft oil/ft	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287	0.00287
			ic	ft oil/ft																
			Av	ft2	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96	642.96
			Ah	ft2																
			Ahs	ft2	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000
			Qo	ft3/d	0.95	0.00	0.36	0.28	0.00	0.07	0.11	0.00	0.00	0.00	0.00	0.00	1.48	1.03	1.25	1.99
			Qo	gal/d	7.10	0.00	2.71	2.10	0.00	0.54	0.79	0.00	0.00	0.00	0.00	0.00	11.05	7.70	9.32	14.85
			Qo/Ah	gal/yr/ft2	0.20	0.00	0.08	0.06	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.31	0.22	0.26	0.42
			Qo direction		SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
			SC	dyne/cm	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0

Notes 1. Positive vertical gradients indicate upward flow direction.
1. Positive vertical gradients indicate upward flow direction.

TABLE B-5
NAPL FLOW CALCULATIONS
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK AND BAXTER
PORTLAND, OREGON

Equations ver 1

Ah =	W*D	6/27/2005
Av =	w*Ho	
bf =	1-gw/go	for DNAPL horizontal io and is gradient calculations
bf =	1-ga/go	for LNAPL horizontal io calculation, approximately = 1.0
io =	bf*(ho2-ho1)/L	for horizontal flow, ft oil/ft (includes is for DNAPL)
io =	(go / gw) - 1	ft water/ft, for vertical flow
ic =	-io	
io =	1- (gw / go)	ft oil /ft, for vertical flow
is =	bf*(hs2-hs1)/L	ft oil/ft, for horizontal flow (included in io for DNAPL)
it =	iw+io+is	
iw =	(hw2-hw1)/L	ft water/ft
iw =	gw*(hw2-hw1)/(go*L)	ft oil/ft
iw =	iw*gw/go	
Ko =	kro*Kosat	
Kosat =	Kwsat*(go/gw)*(uw/uo)	
Kro =	kroe*Son^no	Corey (1956)
Q =	Ko*it*Av	
Son =	(So-Sro)/(1-Sro-Srw)	
So (mob) +	(So(max) - Sro)/2	
SC =	saw-(snw+san)	Cohen and Mercer (1993)
	NAPL will spread as a film between air and water phases if S > 0.	

Conversions

1 ft3 =	7.48 gal
1 ft =	0.3048 m
1/ft =	3.2808 1/m

Variables

a	van Genuchten coefficient for air-water (1/ft or 1/m)
Ah	horizontal cross-sectional area of vertical flow path
Ahs	horizontal area of seepage area
Av	vertical cross-sectional area of horizontal flow path
bf	oil bouyancy factor
D	horizontal depth normal to W: 1) of flow path for vert. flow; 2) of seepage area for hor. flow
ga	density of air (g/cc)
go	density of oil (g/cc)
gw	density of water (g/cc)
Ho	vertical thickness of oil layer in well or core (ft)
Ho (mob)	vertical thickness of oil at So > Sro in well or core (ft)
ho1	oil hydraulic head at point 1
ho2	oil hydraulic head at point 2
hs1	stratigraphic elevation at point 1
hs2	stratigraphic elevation at point 2
hw1	groundwater hydraulic head at point 1
hw2	groundwater hydraulic head at point 2
ic	critical gradient required for oil flow
io	oil gradient (ft of oil/ft)
is	stratigraphic gradient
it	total gradient
iw	hydraulic gradient for water (cap)
Ko	hydraulic conductivity for oil
Kosat	saturated hydraulic conductivity for oil (cap)
kro	relative permeability
kroe	relative permeability endpoint
Kwsat	saturated hydraulic conductivity for water
L	length of flow path (vertical or horizontal)
n	porosity
N	van Genuchten empirical coefficient
no	exponent
Qo	oil discharge (ft^3/d or gal/d)
SC	spreading coefficient
sao	air-oil interfacial tension
saw	air-water interfacial tension
So (avg)	average oil saturation
So (max)	maximum oil saturation
So (mob)	average oil saturation in vertical thickess with So>Sro
Son	normalized oil saturation
sow	oil-water interfacial tension
Sro	residual oil saturation
Srw	residual water saturation
uo	viscosity of oil (cp)
uw	viscosity of water (cp)
W	horizontal width of flow path

TABLE B-6
SHORELINE NAPL BALANCE
INNOVATIVE TECHNOLOGY EVALUATION
McCORMICK & BAXTER SUPERFUND SITE

values changed from previous version

Flow Path 1. FWDA to Willamette Cove

	Variable	Units	Cold Water Flood			Hot Water Flood			ISCO			ERH			Current Condition With Single-Phase Extraction			Current Condition Without Extraction
			Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	
Input	Ah	ft2	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400	22400
	Ahs	ft2	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150
	Ho (initial)	ft	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21
	Ho (mob)	ft	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
	So (initial avg)		0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
	So (mob)		0.081	0.036	0.063	0.060	0.018	0.050	0.052	0.000	0.010	0.010	0.000	0.001	0.102	0.094	0.098	0.103
	Sro		0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.1	0.1	0.1	0.086
	n		0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402
	Qo	**ft3/d**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0066**	**0.0014**	**0.0035**	**0.0075**
	Qo/Ah	ml/min/ft2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	pbc	lb/ft3	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
	Ko	kg/kg	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	go	(g/cc)	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947	0.9947
	xo	ft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Results	Qo/Ah	gal/yr/ft2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.72E-03	1.23E-03	3.02E-03	6.55E-03
	Qo/Ah	ft3/d/ft2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-06	4.48E-07	1.11E-06	2.40E-06
	go	lb/ft3	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07	62.07
	Vo (initial)	ft3	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885	3885
	Vo (mob)	ft3	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	355
	td	d	0	0	0	0	0	0	0	0	0	0	0	0	7485	0	0	47049
	td	yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5	0.0	0.0	128.8
	tc	d	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	215,282	1,005,987	407,667	188,215
	tc	**years**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**589.4**	**2754.2**	**1116.1**	**515.3**

6. TFA to Willamette River

	Variable	Units	Cold Water Flood			Hot Water Flood			ISCO			ERH			Current Condition With Single-Phase Extraction			Current Condition Without Extraction
			Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	
Input	Ah	ft2	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
	Ahs	ft2	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000	13000
	Ho (initial)	ft	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23
	Ho (mob)	ft	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21
	So (initial avg)		0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
	So (mob)		0.193	0.086	0.151	0.143	0.042	0.119	0.124	0.000	0.025	0.025	0.000	0.002	0.222	0.198	0.210	0.247
	Sro		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	n		0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406
	Qo	**ft3/d**	**0.9493**	**0.0000**	**0.3617**	**0.2809**	**0.0000**	**0.0727**	**0.1060**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**1.477**	**1.030**	**1.246**	**1.986**
	Qo/Ah	ml/min/ft2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	pbc	lb/ft3	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
	Ko	kg/kg	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	go	(g/cc)	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952	1.0952
	xo	ft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Results	Qo/Ah	gal/yr/ft2	2.00E-01	0.00E+00	7.60E-02	5.90E-02	0.00E+00	1.53E-02	2.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.11E-01	2.16E-01	2.62E-01	4.17E-01
	Qo/Ah	ft3/d/ft2	7.30E-05	0.00E+00	2.78E-05	2.16E-05	0.00E+00	5.59E-06	8.15E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-04	7.92E-05	9.59E-05	1.53E-04
	go	lb/ft3	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34	68.34
	Vo (initial)	ft3	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884	7884
	Vo (mob)	ft3	2421	0	1325	1131	0	486	615	0	0	0	0	0	3191	2547	2869	3841
	td	d	2551	0	3663	4027	0	6684	5804	0	0	0	0	0	2160	2472	2302	1934
	td	yr	7.0	0.0	10.0	11.0	0.0	18.3	15.9	0.0	0.0	0.0	0.0	0.0	5.9	6.8	6.3	5.29
	tc	d	5,611	infinite	14,727	18,961	infinite	73,246	50,257	infinite	infinite	infinite	infinite	infinite	3,605	5,171	4,274	2,682
	tc	**years**	**15.4**	**infinite**	**40.3**	**51.9**	**infinite**	**200.5**	**137.6**	**infinite**	**infinite**	**infinite**	**infinite**	**infinite**	**9.9**	**14.2**	**11.7**	**7.3**

GeoEngineers

Appendix C
DEQ Response to Comments

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RESPONSE TO COMMENTS

Innovative Technology Evaluation Report

McCormick and Baxter Creosoting Company Superfund Site

Since initiation of the Innovative Technology Evaluation (ITE) in November 2004 the Department of Environmental Quality (DEQ) has sought input from the U.S. Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and Environment International, Inc. (Tribes) representing the Confederated Tribes of the Grand Ronde Community of Oregon, the Confederated Tribes of Siletz Indians of Oregon, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Nez Perce Tribe and the Confederated Tribes and Bands of the Yakama Nation. This input included initial discussions in developing the scope of the ITE, review and comment on the ITE work plan, and review and comment on the ITE report. Additionally, DEQ and GeoEngineers/Aquifer Solutions, Inc. provided status presentations at numerous project meetings. DEQ believes this level of coordination has resulted in a final ITE report that addresses, to the extent possible, the interests and concerns of the various entities.

In order to facilitate the timely completion of the ITE report, DEQ has provided the following responses to comments submitted by NOAA and EI on the draft ITE report. Many of the comments resulted in changes to the ITE report. Although several comments requested more analysis or study to be performed, DEQ, in consultation with EPA, NOAA and EI, concluded that this additional information likely would not effect the primary conclusion that implementation of innovative technologies for NAPL recovery would not be cost effective. Thus reworking the document, although it would improve the comparability of the technologies, is not a valuable use of the available resources to apply to the project.

**DEQ Response to
NOAA Comments on the Draft Innovative Technology Evaluation
of McCormick & Baxter**

The comments were submitted by Robert Neely, NOAA Coastal Resource Coordinator, Region 10.

General Comments

Comment 1:
The document is well organized, well written, and provides a fair comparison of four innovative NAPL treatment technologies on a general, abstract, conceptual basis. However, the review does a poor job of identifying and incorporating limiting factors that are specific to the McCormick and Baxter site, in particular the proximity of the areas needing treatment to the Willamette River. The Willamette River presents particular hydraulic control constraints, because of its size and irregularly fluctuating water elevations. The treatment areas not only discharge NAPL creosote to the river, but also continue to discharge groundwater with dissolved PAHs and metals. Failure to maintain total hydraulic isolation of a treatment area could increase the loading of dissolved organic and metal contaminants to the River. There isn't any mention of the risk to salmon populations in the River that are listed as threatened under the Endangered Species Act. Overall, the difficulty and costs of implementing the innovative technologies are underestimated because of these oversights, and therefore the innovative technologies are made to look much more appealing in relation to the existing remedy than is realistic.

DEQ Response:
Comment noted.

Specific Comments

Comment 1:
Pg. 1: It is indicated that the 2002 ESD stated: "*...pilot testing of innovative technologies and enhancement of the existing recovery system will be reconsidered after the barrier wall has been implemented and NAPL discharge contained.*" NAPL discharge is not entirely contained as indicated by the continued recovery of NAPL in monitoring wells outside of the barrier wall (EW-10s, MW-20i, MW-Ds, MW-Gs,), and by the groundwater response in well 36s relative to the elevation of the Willamette River (see NAPL recovery report and transducer plots for meeting of Nov.8, 2005).

DEQ Response:
Comment noted. The ITE fulfills the requirements of the ROD and ESD for evaluating innovative technologies. In evaluating the feasibility of various innovative technologies, the ITE specifically considers the "implementation risk" in potentially mobilizing NAPL that is not contained within the barrier wall.

Comment 2:
Pg. 2, Sec. 1.2.1, Technology Screening: This indicates that at least ten potential technologies were initially screened for potential incorporation into the existing remedy; with only four technologies considered for a more complete, site-specific evaluation in the ITE. This report should briefly document the reason(s) for eliminating a technology from further consideration.

DEQ Response:
Revision made to text. See Section 1.2.1 where the following sentences were added: "*Table 1 briefly documents the reason(s) for eliminating, or retaining, a particular technology from further consideration.*" and "*The technologies were reviewed by the EPA and their partners prior to determining the final technologies to retain for the detailed analysis*".

Comment 3:
Pg. 3, Sec. 1.2.2, Detailed Feasibility Evaluation: "*For the detailed evaluation discussed in this document, the ITE defined and described each retained technology. A deployment configuration was developed for each alternative and used as a base case for the comparison of each of the retained technologies to one another.*" It isn't clear if the deployment configuration means a treatment train, and/or locations for specific remedy components; nor whether the deployment configuration evaluated is for a pilot scale test, or for complete remediation of the McCormick and Baxter site.

DEQ Response:
Revision made to text. See Section 1.2.2 where the following language was added: "*A unit cell approach that is described in Section 4.1 was developed to evaluate each technology on a range of scales, i.e. pilot scale to full-scale. Due to the limited site-specific data available for the performance of many design variables, this approach was deemed to balance uncertainties in each technology and a range of values was provided (see Table 2 to 5) for most cost variables. Conceptually one unit cell could represent a pilot test while the maximum number of unit cells would treat each focus area, see Section 4.1, completely. The user of the ITE can use the information contained herein to evaluate numerous configurations of each technology within each focus area given the information contained within the ITE however an exhaustive analysis and description of every possibility is beyond the resources and scope of the ITE.*"

Comment 4:
Pg. 7, Sec. 2.3.3, Willamette River Stages..., last sentence: "*Based on hydrographs presented in the draft updated CSM (DEQ, 2005), the intermediate and deep water bearing zones are in direct communication with the river.*" The transducer data for well 36s, located inside the wall near the FWDA, shows the shallow water-bearing zone also is in direct communication with the river (transducer plot for progress meeting of November 8, 2005. Notice how recent groundwater elevation peaks in MW-36s correspond to river elevation peaks without time lagging.).

DEQ Response:
Noted.

Comment 5:
Pg. 7, Sec. 3, Focus Areas and NAPL Properties: "*...there are two areas with observed mobile NAPL occurrence outside of the barrier wall: 1) down-gradient of the former waste disposal area (FWDA) and 2) located outside of the former tank farm area (TFA). These are areas where active seeping was observed post-barrier wall construction ... (and) 1 ft of granular organoclay was emplaced within the sediment cap to sorb the NAPL prior to reaching the River ... are the focus areas of this ITE.*" These areas do not have hydraulic control, and it is not certain that NAPL migration is contained; thus it is arguable whether the ESD pre-condition for innovative treatment is present at these locations.

DEQ Response:
See DEQ's response to Comment 1.

Comment 6:
Pg. 7, Sec. 3.1 Former Waste Disposal Area and Figure 5: "*The subsurface between the barrier wall and Willamette Cove is underlain by alluvial sands (Figure 5) with a gravel zone coincidental with the water table. The gravel zone appears to provide a preferential pathway for groundwater and LNAPL migration to Willamette Cove. The lateral extent of ?NAPL in this area corresponds to an area approximately 250 ft square (Figure 5).*" There are both **L**NAPL and **D**NAPL in this area. Only the lateral extent of the LNAPL has been established, and the statement should be specific to LNAPL.

DEQ Response:
Revision made to text. See Section 3.1, 2nd paragraph. L was added to the NAPL as DEQ is referring to LNAPL.

Comment 7:
Pg. 7, Sec. 3.1 Former Waste Disposal Area and Figure 5: Figure 5 inappropriately assumes the DNAPL found in MW-20i does not extend downward or river-ward from the wellscreen. The extent of DNAPL around this wellscreen is unknown, but substantial quantities of DNAPL have been removed, and continue to be removed, suggesting sufficient upgradient DNAPL to maintain mobility (approximately 6 gal of DNAPL was recovered from MW-20i in both Sept and Oct 2005). The figure should indicate broader extent of DNAPL surrounding this wellscreen, with unknown delineation of the edges, especially toward the river. Since DNAPL is being recovered from MW-Gs and MW-Ds, also; why not use their well screen depths and boring logs to add additional information to this figure?

DEQ Response:
Figure 5 was revised to add the uncertainty in DNAPL extent.

Comment 8:
Pg. 12, Sec. 5.2, Current Condition: *"With respect to the ITE focus areas, approximately 11 gallons of LNAPL per month are extracted from Flowpath 1, which is LNAPL outside the barrier wall in the FWDA migrating to Willamette Cove."* Why isn't the DNAPL along this flowpath considered? From June 2005 through October 2005, total LNAPL recovered from outside the barrier wall toward Willamette Cove was 13.5 gallons while total DNAPL was 54.5 gallons (Data from electronic table: Thickness and Extraction Sum, prepared by E&E for meeting of November 8, 2005. Data from monitoring reports for Feb and March, 2005 indicate about 10 gal/wk (average) DNAPL was removed from MW-20i and 1.5 gal/wk DNAPL from nearby MW-Ds.

DEQ Response:
Noted. There is no evidence that the DNAPL is migrating into the River. Based on the appearance of DNAPL in the shallow wells MW-Ds and MW-Gs and then it's occurrence at a much deeper depth in MW-20i, it appears to primarily be migrating downward. DEQ does recognize that there is substantial uncertainty in the DNAPL migration in the FWDA outside of the barrier wall.

Comment 9:
Pg. 12, Sec. 5.2, Current Condition, bullet 3: *"Techniques that assist flow of ?NAPL into recovery wells include dual recovery of groundwater and NAPL by separate pumps to increase the gradient toward the recovery wells, ..."* Is this is a technique that works for LNAPL, but not for DNAPL? Because both LNAPL and DNAPL occur at the site, any technique should be specified as applicable to LNAPL, or DNAPL, or both. As noted earlier in these comments, most of the recovered NAPL outside the FWDA is DNAPL, and pg. 9, Sec. 3.3.2 of the ITE indicates the NAPL at the TFA seep also is DNAPL.

DEQ Response:
Noted. The following language was added to section 5.2: "*Techniques that assist flow of NAPL into recovery wells include dual recovery of groundwater and NAPL by separate pumps to increase the gradient towards the recovery wells, or low continuous pumping of NAPL at a flow rate equal to the rate that NAPL enters the well to maintain flow paths to the extraction wells and recover as much as possible using single phase extraction. These approaches tend to improve LNAPL recovery more than DNAPL recovery however both LNAPL and DNAPL recovery may be improved by increasing NAPL or hydraulic gradients toward extraction systems.*"

Comment 10:
Pg. 12, Sec. 5.3, Innovative Technology 1, Cold Water Flooding: "*Through simultaneous injection of treated groundwater and extraction of groundwater, hydraulic gradients are increased, NAPL is mobilized, and flow occurs faster and to lower saturation*" How does the fluctuating elevation of the Willamette River (with tides and seasonally) affect our ability to maintain a hydraulic gradient to the extraction wells? Page 7 notes that seasonal water level changes average 10-15 ft.

DEQ Response:
Comment noted. The system design would need to account for the large variation in the water table. The proximity to the River has design ramifications for each of the enhanced technologies. However, beyond noting that in this report, the level of effort was not such that a detailed design and associated costs could be estimated for this report. Language was added to note the affect that the variation in water levels could have on the technology.

Comment 11:
Pg. 12, Sec. 5.3, Innovative Technology 1, Cold Water Flooding: "*... Extracted groundwater and NAPL would be conveyed to a treatment system.*" Because of the proximity and hydraulic connection to the Willamette River, the collection system will likely entrain river water, which will also need treatment because it has been mixed with NAPL. That is, without complete hydraulic control, the volume of water needing treatment may be much greater than estimated, which could greatly increase costs.

DEQ Response:
Comment noted. Extraction and treatment of River water would be more of an issue for the TFA than the FWDA where the wells and NAPL are located further back from the River.

Comment 12:
Pg. 13, Sec. 5.3, Innovative Technology 1, Cold Water Flooding: "*Figure 8 illustrates the conceptual well field in plan view.*" Figure 8 is a schematic for each of the technologies but it does not locate the unit cells on the McCormick and Baxter site. These systems would need to be placed adjacent to a large volume river that experiences tidal and seasonal fluctuations in water elevation. How would hydraulic control be established during IT treatment, and what is the estimated cost?

DEQ Response:
See response to Comment 10.

Comment 13:
Pg. 13, Sec. 5.3, Innovative Technology 1, Cold Water Flooding: "*Preliminary screen intervals are shown in Table 2.*" It isn't clear whether these are depths below ground surface (bgs) or relative to some datum, such as NGVD or CRD. This is significant, since we don't know where the unit processes are placed on the site. The screen depth/interval for MW-20i, where the greatest volume of NAPL accumulates, is 50-70 ft bgs, 20 – 40 ft below the water table (well log for MW-20i, pages E-33 to E-35 in Appendix C of the CSM).

DEQ Response:
All tables were changed to feet NGVD.

Comment 14:
Pg. 13, Sec. 5.4, Innovative Technology 2, Hot Water Flooding: "*Although the change in (NAPL) specific gravity is negligible, some of the DNAPL may become LNAPL, possibly providing some benefit for capture, although neutral buoyancy is expected.*" If NAPL viscosity and buoyancy are reduced, the capacity for DNAPL to move horizontally with groundwater is increased. As noted previously, a relatively large volume of DNAPL has been recovered outside the wall toward Willamette Cove, and the TFA seep

also appears to be DNAPL. If the effect of the heating exceeds the depth and/or area of hydraulic capture, DNAPL can be mobilized toward the river. In addition, as noted in the text, heating the subsurface will increase the solubility of NAPL constitutents in groundwater, and any groundwater escaping from the area of treatment will discharge an increased concentration of dissolved constituents to the river.

DEQ Response:
Comment noted.

Comment 15:
Pg. 14, Sec. 5.4, Innovative Technology 2, Hot Water Flooding: *"Extraction well flow rates were calculated, see Appendix A, from estimates of hydraulic conductivity neglecting constant head boundaries..."* This should be explained in language that an educated layperson can understand. This means the estimates ignored the proximity of the treatment system to a very large river, and the difficultly in establishing a hydraulic gradient away from the river, which is a necessary component of any of the proposed technologies. In order to maintain the hydraulic gradient and prevent leakage back into the river, the isolation/pumping system would need to be robust enough to overcome the gradient from the maximum anticipated river elevation.

DEQ Response:
The language was changed as follows to clarify: "*Extraction well flow rates were calculated, see Appendix A, from estimates of hydraulic conductivity neglecting constant head boundaries and relative permeability behavior. Flooding technologies would require extensive hydraulic analysis and testing prior to field deployment to further evaluate the competing effects of the fluctuating head imposed by the Willamette River, no flow boundary imposed by the sheet pile wall, vertical flow from below, and superposition effects of nearby wells that could not be considered within the scope of the ITE.*"

Comment 16:
Pg. 14, Sec. 5.5, Innovative Technology 3, In-situ Chemical Oxidation: "*The mass of NAPL in the subsurface is subject to uncertainty, therefore stoichiometric calculations of ozone requirement were not possible at this time. ... The ozone concentration will be high due to the large mass of organics within the NAPL.*" This suggests a risk of only partial oxidation, which has potential to increase the toxicity of the PAH constituents of the NAPL. For example, it is the partially metabolized PAHs that are most toxic to fish, and it has been demonstrated that PAHs partially oxidized by UV radiation exhibit increased toxicity relative to the parent compound.

DEQ Response:
The review's comment is contrary to publications by Langlais, et al, 1989; Legube, et al, 1981; and Stephenson et al, 1979 indicating that partial oxidation products tend to have lower toxicity and improved biodegradability as compared to parent PAH compounds.[1] Nevertheless, the following language was added

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[1] Langlais, B., B. Cucurou, Y. Aurelle, B. Capdeville, and H. Roques, 1989. "Improvement of a Biological Treatment by Prior Ozonation", *Ozone Sci. & Eng.*, Vol. 11, pp. 155-168.

Legube, B., B. Langlais, B. Sohm, and M. Dore, 1989. "Identification of Ozonation Products of Aromatic Hydrocarbon Micropollutants: Effect on Chlorination and Biological Filtration", *Ozone Sci. & Eng.*, Vol. 3, pp. 33-48.

Stephenson, P., A. Benedek, M. Malaiyandi, and E. Lancaster, 1979. "The Effect of Ozone on the Biological Degradation and Activated Carbon Adsorption of Natural and Synthetic Organics in Water. Part I. Ozonation and Biodegradation" , *Ozone Sci. & Eng.*, Vol. 1, pp. 263-279.

to incorporate the potential risk of partial oxidation: "*The ozone demand will be high due to the large mass of organics within the NAPL and the potential exists for partial oxidation of PAH compounds, some of which may possess increased toxicity.*"

Comment 17:
Pg. 15, Sec. 5.6 Innovative Technology 4, Electrical Resistive Heating: "*The design hydraulic gradient required to maintain hydraulic control was the same as that used for cold and hot water flooding.*" That is, hydraulic control at the shoreline of the river is a requirement of this technology, also, but nowhere does this document describe how hydraulic control will be established and maintained for the duration of treatment, or the associated costs.

DEQ Response:
Noted. Each technology had a unique duration and thus although the costing was the same for the hydraulic containment, the time to run the system was varied to estimate the operational costs.

Comment 18:
Pg. 16, Sec. 6.1, Current Condition, Discontinue Extraction, Long-term Reliability: "*This approach would not increase the long-term reliability of the current remedy.*" This is a misleading understatement. Because NAPL currently is extracted from several wells, predominantly DNAPL from between the barrier wall and the BNSF embankment, the pore pressure on any NAPL in this area is periodically reduced, relieving some of the forces contributing to NAPL migration. If NAPL recovery is eliminated, the mobility of the remaining NAPL may be increased over current conditions, and the volume of NAPL with potential to migrate to the river similarly increased. That is, this approach would reduce the long term reliability of the remedy in proportion to the total volume of NAPL otherwise extracted from the wells. (See comment regarding pg. 12, Sec 5.2, Current Condition for weekly DNAPL volumes removed.)

DEQ Response:
Noted. "Reduce" was added to the sentence to read "*This approach may reduce the long-term reliability of the current remedy.*"

Comment 19:
Pg. 16, Sec. 6.2, Current Condition and Single Phase Extraction: "*NAPL is currently extracted monthly from six wells outside of the barrier wall when NAPL accumulates to thicknesses of greater than 0.4ft. in a well.*" As of November 1, 2005, NAPL extraction data indicate the wells are checked weekly rather than monthly. Weekly checking and extraction is noted in Sec. 5.2 of the ITE.

DEQ Response:
Revised to "weekly".

Comment 20:
Pg. 17, Sec. 6.2.1, Effectiveness: "*A large area of NAPL occurrence in the FWDA under the high pressure sewer main and BNSF railroad trestle would remain unavailable for NAPL recovery.*" I agree, but what isn't indicated is whether this is LNAPL or DNAPL. Much greater volumes of DNAPL have been removed, and DNAPL continues to accumulate at greater volumes than does the LNAPL. NAPL that is still mobile is a greater concern than residual NAPL, and the data from MW-20i suggests that there is considerable mobile DNAPL between the barrier wall and the BNSF embankment, and an unknown quantity of mobile DNAPL and LNAPL between the BNSF embankment and Willamette Cove.

DEQ Response:
NAPL was revised to LNAPL and DNAPL as both would remain unrecovered under the RR trestle.

Comment 21:
Pg. 17, Sec. 6.2.2, Long-term Reliability: While this remedy is not as reliable as one that removes all mobile LNAPL and DNAPL from the subsurface, the long-term reliability is greatly enhanced by the use of organo-phyllic clay to intercept and sequester the NAPL before it reaches the sediment surface and river. What is uncertain regarding this remedy is whether o-p clay is located to intercept all NAPL that would otherwise discharge to the river, and whether there is adequate o-p clay to sequester the NAPL indefinitely.

DEQ Response:
Comment noted. The uncertainty will primarily be addressed through continued monitoring of the remedy over many years. Definitive evaluation of NAPL migration at a site is nearly impossible and DEQ does not have any in-water evidence to suggest an additional DNAPL flowpath to the River. However, DEQ also recognizes that although there is substantial amount of data for the site, elimination of all potential flowpaths through data collection has not been achieved.

Comment 22:
Pg. 17, Sec. 6.2.5, Cost: *"Tables B-3 and B-4 in Appendix B provide the cost details for single-phase NAPL recovery in the TFA and FWDA."* It appears the titles of these two tables were interchanged. The only difference I noticed was the addition of three new wells in Table B-3, which is titled, Single-Phase NAPL Extraction Cost Summary – TFA. There should be discussion in the text regarding the purpose and proposed locations of these three new wells.

DEQ Response:
Table B-3 was revised to include the installation of 3 extraction wells. Three wells were selected to provide general coverage across the extent of the DNAPL seep area outside the barrier wall in the TFA area because there are no existing wells.

Comment 23:
Pg. 18, Sec. 6.3.3, Cold Water Flooding, Implementability: *"Additional hydraulic design would be required to evaluate the effects of the Willamette River as a constant head boundary..."* The Willamette River is a fluctuating hydraulic boundary that experiences diurnal tides and annual elevation changes of 10-15 ft. This site condition needs to be incorporated as a precondition for evaluation of each technology, including the additional implementation cost, not merely 'tacked on' as an afterthought.

DEQ Response:
The fluctuating head was not taken into account as it is more detailed than this report was designed to evaluate. It was however qualitatively considered under Implementability. "Constant" head was changed to "fluctuating " head boundary.

Comment 24:
Pg. 18, Sec. 6.3.4, Cold Water Flooding, Implementation Risk: *"The implementation risk of cold water flooding is moderate to low based on expected hydraulic control of the system."* Again the evaluation is incomplete because the difficulties of getting hydraulic control in proximity to the river were not incorporated. This is not a minor oversight, and is likely to alter whether any of these innovative technologies is feasible outside the barrier wall. Hydraulic control is not complete within the wall, either, because of the connection to the river at the FWDA corner where the silt layer "pinched out". This is documented by comparing recent transducer data for the river and MW-36s.

DEQ Response:
Noted.

Comment 25:
Pg. 19, Sec. 6.3.5, Cold Water Flooding, Cost: This does not describe how hydraulic control will be accomplished in the locations where NAPL continues to migrate toward the River, nor the associated costs.

DEQ Response:
Noted. A detailed design was beyond the scope of this document. Although water flooding may not need to achieve total capture – it would only need to control for the water that is injected. For the FWDA, in the small area just outside the barrier wall, this may be achievable without pumping significant amounts of water from the River.

Comment 26:
Pg. 20, Sec. 6.4.3, Hot Water Flooding, Implementability: *"Additional hydraulic design would be required to evaluate the effects of the Willamette River as a constant head boundary..."* The Willamette River is a fluctuating hydraulic boundary that experiences diurnal tides and annual elevation changes of 10-15 ft. This site condition needs to be incorporated as a precondition for evaluation of each technology, not merely 'tacked on' as an afterthought.

DEQ Response:
"Constant" head boundary was changed to "fluctuating" head boundary.

Comment 27:
Pg. 20, Sec. 6.4.4, Hot Water Flooding, Implementation Risk: *"The implementation risk of hot water flooding is moderate to low based on expected hydraulic control of the system."* Please see comment above for Sec. 6.3.4, Cold Water Flooding, Implementation Risk. In addition, hot water flooding increases the concentration of dissolved creosote components in groundwater, so that groundwater escaping from the system and discharging to the River will be at a higher contaminant concentration than for cold water flooding or for the existing remedy. What will be the effect of subsurface heat on the organo-phyllic clay?

DEQ Response:
Revised as follows to note the added effect of increased dissolved phase in groundwater: "Hot water flooding will carry increased implementation risk compared to cold water flooding because heated groundwater may serve mobilize increased discharges of dissolved phase NAPL constituents."

Comment 28:
Pg. 20, Sec. 6.4.5, Hot Water Flooding, Cost: This evaluation should describe how hydraulic control will be accomplished in the locations where NAPL continues to migrate toward the River, and include the associated costs.

DEQ Response:
Although prescribed locations for wells are not indicated, an estimate of the number of modules (a range is used) required to recover NAPL from the two areas where NAPL continues to migrate into the organoclay within the sediment cap was estimated as costs for the remedy are based on that number of modules. These represent the high and low costs in Table 7.

Comment 29:
Pg. 21, Sec. 6.5.1, In-Situ Chemical Oxidation, Effectiveness: *"The ozone would be pulsed into injection wells in groups to maximize the biodegradation component while minimizing displacement of NAPL as a result of gas injection."* This seems like a difficult trade-off. Displacement of the NAPL could increase migration to the river or organo-phyllic clay; and insufficient ozone treatment may leave toxic

residuals that are as toxic, or more toxic, than the PAHs in the creosote. Proximity to the River increases the risk of environmental harm if the process does not continuously operate at optimum.

DEQ Response:
Comment noted.

Comment 30:
Pg. 21, Sec. 6.5.2, In-Situ Chemical Oxidation, Long-term Reliability: *"The long-term reliability of the ISCO using ozone gas is moderate to high dependent on the size of the ozone generation system and the heterogeneity of the subsurface."* That is, a heterogenous subsurface reduces reliability of the system. The filled floodplain that constitutes the nearshore of McCormick and Baxter is not homogenous, or we would not have a gap under the barrier wall, DNAPL discharging along the shoreline at the TFA, and a hypothesis that a historic stream is the conduit for LNAPL from the FWDA to Willamette Cove. There also are divalent cation (metal) contaminants at McCormick and Baxter that would become more soluble when oxidized, i.e., groundwater concentrations of copper and zinc would increase with ISCO.

DEQ Response:
Comment noted.

Comment 31:
Pg. 22, Sec. 6.5.4, In-Situ Chemical Oxidation, Implementation Risk: *"Operations of an ozone-based ISCO process would begin with low flow rate injection along the river to isolate NAPL from the river. Additional design analysis would be required to prevent NAPL displacement and evaluate the need for NAPL-groundwater recovery, treatment and discharge with an ozone-based ISCO system."* How will NAPL be isolated from the river, when it already discharges to the river? Some of the NAPL will be pushed toward the river, with the potential to cause an increased loading rate for the sediment cap and organo-phyllic clay.

DEQ Response:
The 1st paragraph describes the design requirements to prevent this. No change.

Comment 32:
Pg. 23, Sec. 6.6.1, Electrical Resistive Heating, Effectiveness: *"ERH at a creosote site will rely on steam displacement, distillation and stripping. Biological activity within the ERH treatment zone also increases with increasing temperature and will continue as the target zone cools down..."* Steam is a method for sterilizing, so doesn't the steam actually kill the biological activity, including micro-organisms? Granted, this would eventually recover, but ERH can enhance microbiological activity only in areas that are warmed, and not cooked.

DEQ Response:
Reference added.

Comment 33:
Pg. 24, Sec. 6.6.4, Electrical Resistive Heating, Implementation Risk: *"The implementation risk of ERH is moderate based on the expected hydraulic control of the extraction system..."* Again, hydraulic control in proximity to a large, fluctuating river is a precondition that should have been incorporated into the evaluation.

DEQ Response:
Comment noted.

Comment 34:
Pg. 25, Sec. 6.6.5, Electrical Resistive Heating, Cost: "*The operating costs for ERH are largely dependent on the duration of the treatment and the subsequent power consumption.* And on pg.24, Sec. 6.6.3, " *Inflow of cold water from the river may result in additional power costs for ERH as compared to applications at other sites.* " Again, the specific condition of being in close proximity to a large, fluctuating River is a major consideration for each of these remedies that should be incorporated into the evaluation.

DEQ Response:
Comment noted.

Comment 35:
Pg. 26, Sec. 6.7.1, FWDA-Willamette Cove: "*Ozone based ISCO is the most appropriate innovative technology for the FWDA area due to the limited presence of NAPL observed .....* " As noted previously, this reviewer believes there is a major oversight of migrating DNAPL around MW-20i. ISCO treatment of DNAPL in this area should be evaluated. However, we also question whether any useful comparison for a site with the specific requirements of McCormick and Baxter can be made based upon comparison of "*10% conceptual designs*" that do not account for the impact of the nearby river in terms of both engineering and risk. No mention is made of resources using the river that are listed as threatened under ESA.

DEQ Response:
Comment noted.

Comment 36:
Pg. 27, NAPL Recovery Efficiencies and Effect on Cap Life: Most of this section is based upon calculations done in the CSM. NOAA provided extensive comments on the CSM and has not had responses to those comments, thus, this section can not be reviewed because it is based on earlier work that has not yet been revised and accepted.

DEQ Response:
Comment noted.

Comment 37:

Suggested editorial changes:

Pg. 4, Sec. 2.1 Site History: "*McCormick and Baxter Creosoting Company was founded in 1944 to produce* treated *wood products (lumber, pilings, railroad ties, etc.) during World War II.* "

DEQ Response:
Change made to text.

DEQ Response to
Tribal Comments on the Draft Innovative Technology Evaluation
of McCormick & Baxter

The comments were submitted on behalf of the Confederated Tribes of the Grand Ronde Community of Oregon, the Confederated Tribes of Siletz Indians of Oregon, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Nez Perce Tribe and the Confederated Tribes and Bands of the Yakama Nation.

General Comments

Comment 1:
The ITE does not evaluate potential NAPL and dissolved contaminant discharge in the FWDA to the Willamette River. For the FWDA, the ITE focuses only on the seep in the Willamette Cove area. The tribes are concerned about potential mobile NAPL presence in the area between the two seeps described in the ITE (see Section 3.1) along the Willamette River near the railroad bridge, for the following reasons:

- previous observations included seeps in the FWDA along this area (see Figure 4-1 of DEQ's draft conceptual site model (CSM))
- at the November 2005 progress meeting, the partners were told that sheen was noticed sometime this summer or fall at the railroad bridge pier
- NAPL, both light and dense fractions, is still being observed in wells EW-19s, EW-10s, MW-34i, MW-Gs, MW-20i, EW-2s, EW-9s and MW-Ds
- groundwater contours show this as a direction of groundwater flow from wells MW-20i and others.

Unfortunately this area does not appear to have been part of the NAPL investigation in 2004. We remain concerned that the mobile NAPL in the FWDA outside of the barrier wall has the potential to move not only to Willamette Cove, but also to the Willamette River. If NAPL were to move to the "corner" of the site, this area does not have an organoclay cap. This potential pathway should be included in the ITE, particularly Table 7, or clarification provided discussing the evidence indicating that this is not a pathway.

DEQ Response:
Comment noted. Since installation of the sediment, we have not observed seeps with sheens entering the Willamette River. We have observed very isolated areas where sheen has been observed associated with ebullition at the site. This appears in a very different fashion than a continuous NAPL seep where sheen burst are observed without gas and emanate from the sediment at a fairly steady consistent rate. The sheen associated with bubbling is intermittent and often during a site visit, it is not even observed.

One of these isolated areas where the occasional sheen burst associated with ebullition was underneath the RR Bridge. This area has been capped with organoclay mats covered by sand and riprap armoring. The final report on the additional capping will be presented in the Remedial Action Construction Summary Reports for the sediment cap and upland soil cap, currently being prepared by Ecology & Environment, Inc. This area will continue to be monitored as part of Operation and Maintenance in the future to ensure that the conceptual model suggesting that this flowpath (from the upland area where NAPL is observed in wells outside the barrier wall in the FWDA to the Willamette River) no longer has sufficient NAPL saturation to actively migrate to the River is valid. If we do observe future seepage of NAPL, the remedy may be to add additional granular organoclay to the sediment cap instead of attempting to remove the NAPL from the upland portion of the site where much of the NAPL is located underneath the RR right-of-way where access is difficult if not inaccessible.

Comment 2:
The unit cell analysis is not sufficient to allow comparison to the current condition cases and whether the remedy approach will be protective. The ITE was completed with only a unit cell analysis. There are two concerns associated with this. First, without an estimate (or a range of estimates) of the amount of NAPL in the

FWDA outside the barrier wall, it is particularly difficult to compare the innovative technologies to the current conditions with and without NAPL extraction. We appreciate that the ITE presents NAPL recovery efficiencies for comparison of the technologies and current condition cases; however, there is a significant difference if the recovery is 52% of 500 gallons rather than of 500,000 gallons. Having estimates of the amount of NAPL would also help focus the discussion regarding uncertainty with the sediment cap's effectiveness. It appears from Table 7 in the ITE that some volume(s) of NAPL has been assumed as there are values for "expected life of the organoclay cap" and "depletion time for mobile NAPL." It would be helpful if the ITE clarified whether these values for the "expected life of the organoclay cap" are based on NAPL or dissolved contaminant concentrations. Because the Record of the Decision for the overall Portland Harbor cleanup site is likely to be more protective, the Tribes are concerned that this sediment cap will not be sufficiently protective of human health and the environment without additional NAPL removal.

Second, the ITE needs to present the timeframes and costs to implement each innovative technology clearly and show how that might benefit the overall site remedy and reduce uncertainty with the sediment cap's effectiveness to keep contaminants from the river. Are the costs in Table 7 total costs for some assumed timeframe of technology implementation?

DEQ Response:
The unit cell approach has been clarified in the text. The sections on innovative technology have been revised to include the timeframes and costs. The total costs shown in Table 7 have been clarified in Section 4.1.2.

Comment 3:
The current condition cases are not adequately presented to allow comparison to the innovative technologies. In the case of the current condition without extraction, the ITE chooses two sediment cap repair methods with two areas for costing purposes. Sufficient detail has not been provided for the reader to understand why these would be the representative solutions to cap failure. There is also no discussion on the possibility that a larger-scale cap repair may be necessary than the two cases presented. Because creosote sheen was observed this summer at various locations in the sediment cap, we are concerned that the cost of cap repairs is not adequately thought through. Will these be one-time repairs or is the problem bigger? Are dissolved contaminant concentrations addressed adequately? Although these are larger questions than the ITE is likely able to answer, they need to be discussed further.

In the case of the current condition with extraction, we are concerned that the well system is not optimized to recover NAPL, particularly in the FDWA outside the barrier wall. In fact, we have a concern that many of the wells in this area may be screened in a groundwater zone too shallow to recover NAPL, particularly dense NAPL (DNAPL).

DEQ Response:
Comment noted. DEQ was assuming that if there is a seep that it would be limited in extent and that the primary seep areas have already been addressed with granular organoclay. The ITE is addressing potential pathways with NAPL migrating from outside the barrier wall to the River. There are only the two areas (outside the FWDA and outside the TFA) where NAPL is observed in the subsurface outside the barrier wall at saturations rendering it mobile. The ITE does not address potential patching that may need to occur based on the gas bubble-transported sheen occurring in areas where there are high saturations of creosote in the sediment underlying the sediment cap. We suspect that the sediment cap repairs conducted in 2005 using the organoclay mats are a one-time repair. There is one other small area that we will continue to watch closely into next summer that may be repaired. The repairs are being conducted solely based on the observation of sheen from the gas bubbles, not because any water quality criteria have been exceeded in surface water. DEQ will continue to monitor for this transport mechanism across the entire sediment cap. DEQ agrees that if it is decided that additional extraction is warranted outside the barrier wall in the FWDA additional wells may need to be installed to effectively recover NAPL. Currently, DEQ does not have any reason to believe that the NAPL observed upland outside the barrier wall is migrating to the River; this is based on visual observation (or lack thereof), porewater and surface water data and lack of NAPL observed in the

monitoring wells closest to the River. The conclusion for the ITE is that continued extraction will take place into the O&M period. Discussion with EPA and their partners are currently underway to determine whether that continued extraction will continue as it currently is being performed or whether an enhancement to the current recovery will be instituted.

Specific Comments

Comment:
Section 3.1 Former Waste Disposal Area (FWDA)
Please include a description of the third seep nearer the railroad bridge (see Figure 4-1 of the draft CSM). Particularly as sheen is being observed at the railroad bridge pier, we disagree that the focus of the ITE should only be on the Willamette Cove seep.

DEQ Response:
A third seep near the RR Bridge has not been observed. What has been observed is creosote coating gas bubbles in an area where there is known high creosote-saturated sediment beneath the sediment cap. This area has been capped with organoclay blankets covered with sand and riprap armoring. DEQ will be observing this area carefully to ensure that the extent of the repair was adequate.

Comment:
Section 5.1 Current Condition, Discontinue Extraction
Please provide further clarification as to the "severity of the breakthrough." At what point would organoclay blankets be sufficient to address the problem and when would a layer of granular organoclay be placed? Would there be a situation where neither of these repairs would be sufficient? Clarification is important on these assumptions as it would affect the cost estimates in the detailed evaluation that is used to compare the technologies.

DEQ Response:
DEQ is currently working with the University of Texas to evaluate the effectiveness of the organoclay blankets. This evaluation is a follow-on to studies of granular organoclay completed by the University of Texas in September 2005. A patch of the blanket in a bubble area will be removed next summer and sent to Dr. Reible at the University of Texas to quantify the sorption capacity of the blankets. One question is whether the organoclay will swell and cause the NAPL to move laterally allowing it to sorb to fresh organoclay. DEQ is confident however that the blankets provide, if not a long-term, a short-term remedy for the sheens associated with the ebullition. DEQ is not aware of another technology which is as cost-effective and implementable associated with the current sediment cap that can provide the same effectiveness for preventing the creosote associated with the ebullition from reaching the River.

Comment:
Section 5.2 Current Condition with Single-Phase Extraction
Please add a sentence in either the first or second paragraph that discusses the concern that current monitoring wells may not be placed in the optimal zones for NAPL recovery. Although the first bullet mentions this, it is an important concern that needs more prominence.

DEQ Response:
Noted, the following sentence was added to the text. "*Generally, the extraction wells that are used for NAPL recovery were originally intended for monitoring, thus although they are placed where NAPL saturations are high, they are not necessarily constructed to optimize NAPL extraction.*"

Comment:
Section 5.5 Innovative Technology 3: In Situ Chemical Oxidation
The second paragraph begins with a reference to "the mass of NAPL." Please clarify what amount of NAPL is being assumed that a continuous supply of oxidant is necessary to treat it.

DEQ Response:
Qualitative clarifications have been made to the text as follows: "*A continuous supply of oxidant to the subsurface was deemed necessary to treat NAPL. ISCO is more commonly used to treat dissolved constituents as compared to NAPL, therefore a larger and continuous supply of oxidant was deemed necessary.*"

Comment:
Section 6.1.5 Cost
The text needs to explain in greater detail why 225 square feet was chosen as the repair area that would receive the organoclay blanket method of repair, and why 1000 square feet was chosen as the repair area if layers of organoclay were to be applied to the sediment cap. How confident can we be in that these are realistic areas (and cost estimates) if no innovative technology is selected and the current NAPL extraction is eliminated?

DEQ Response:
The following text was added to clarify the areas used and how the cost estimate was determined: "*Two potential repair scenarios were chosen to attempt to span the range of potential costs. The organoclay blankets are less expensive, thus a small patch area (225 sq. ft.) for using the blanket was chosen as the low cost end. For the high cost end, a large area (1000 sq. ft.) using granular organoclay which is more expensive to place was selected to obtain a representative range of cap repair costs using organoclay. The costs are based on actual organoclay placement costs at the site in 2004 and 2005.*"

Comment:
Section 6.2.5 Cost
The text needs to explain why three new wells were chosen for the tank farm area (TFA) and none for the FWDA. We believe that DNAPL recovery may be greater and more effective with better placement of recovery wells in the FWDA.

DEQ Response:
Noted, see Section 6.2.5 where the following text was added: "*Costs for single phase recovery in the TFA and FWDA are based on known costs at the site for similar activities. Costs are similar for each area, except the cost summary for the TFA assumes 3 additional recovery wells will be installed in the TFA area to provide coverage for NAPL recovery.*" Wells already exist in the FWDA where NAPL extraction is ongoing but there are no wells outside of the barrier wall in the TFA area, thus the addition of wells in the TFA and not the FWDA. The addition of extraction wells to the FWDA (outside the barrier wall) is an option if it is determined that enhanced NAPL recovery in the FWDA is required. This ITE only compares the basic current technology of manual recovery to the innovative technologies. Enhancement of the current technology will be considered if it is determined, as DEQ recommends, that the innovative technologies are not implementable, cost-effect and without high implementation risk to an already protective remedy.

Comment:
Section 7.0 Cost-Benefit Analysis
Please clarify how the costs in Table 7 are derived. Are these total costs based on some timeframe of implementation of each technology? The values do not directly correspond to the individual values on Tables 2

through 5 and Tables B-3 and B-4. Why is there a difference for the high cost for alternative 1 between areas? For reasons stated in other comments, we believe that the high cost for alternative 1 may be too low.

DEQ Response:

Timeframes added throughout the text. Alternative 1 costs in Table 7 are the same for the 2 areas. They represent the cost to repair the cap using organoclay. It is difficult to estimate the area that may need to be repaired and there is a potential that the area would be larger than the 1000 ft^3 estimated, but even double that area would be significantly less than any of the innovative technologies. The costs for single-phase extraction differ between the areas because the TFA does not have any existing wells and thus extraction wells would need to be installed. DEQ understands that to enhance the current extraction from the FWDA, additional extraction wells would also need to be installed. This scenario was not estimated for this ITE. This report was produced to determine whether an innovative technology should be applied at the site for NAPL recovery. The question of whether to continue NAPL extraction, cease NAPL extraction, or enhance NAPL extraction using conventional hydraulic methods, will be determined separate from this report.

Comment:

Section 7.1 NAPL Recovery Efficiencies and Effect on Cap Life

This section does not adequately explain Table 7. Please clarify why the NAPL discharge rates for the FWDA flow path are "0." Please clarify why there are NAPL discharge rate entries of "0" for the TFA flow path.

DEQ Response:

Noted, see clarification in text.

Comment:

Section 7.1 NAPL Recovery Efficiencies and Effect on Cap Life

Please clarify if the "expected life of the organoclay cap" is based on NAPL or dissolved contaminant concentrations. The column that is titled "depletion time for mobile NAPL" really should be a calculation based on dissolved contamination. There is concern that the sediment cap may isolate NAPL from the river but may not remove the dissolved contaminant concentration that will continue to contaminate the river through the sediment cap. Because the Record of the Decision for the overall Portland Harbor cleanup site is likely to be more protective, the Tribes are concerned that this sediment cap will not be sufficiently protective of human health and the environment without additional NAPL removal. Please also clarify the meaning of a "0" for depletion time. For example, for cold water flooding in the TFA, please explain why there is a "minimum" of 7 years, a "maximum" of 0 years and an "expected" of 10 years.

DEQ Response:

The ITE focuses on NAPL recovery technologies and does not evaluate dissolved phase contamination. However, if we were to examine the effect of the dissolved-phase on the organoclay life, the contaminant mass in NAPL is much greater than that of dissolved-phase contamination, and thus the dissolved phase would not be expected to significantly change the estimated life expectancy of the cap. The question of overall protectiveness, particularly relative to the Portland Harbor Superfund Site, is beyond the scope of the ITE Report. Rather, the protectiveness of the McCormick & Baxter remedies will be evaluated during the Five-Year Reviews.

Comment:

Section 8.0 Conclusions

At this point, the Tribes cannot agree "that the current condition remains a protective alternative." Particularly with the presence of creosote sheens in various portions of the cap this summer, we have concerns that modeling done to estimate organoclay cap life may not have adequately addressed all the processes at the site, such as tidal pumping during low river water stages. We agree that there is uncertainty associated with the sediment cap. However, we ask that the following sentence be rephrased, particularly as creosote sheen has already been observed through the sediment cap and DEQ has added additional organoclay blankets at the site: "[t]hus, there is uncertainty whether the cap would ever need to be repaired due to NAPL break-through along these flow paths." Finally, until we continue the discussion on the general points that are raised in this comment letter, we can neither agree nor disagree that the correct solution is to continue the current remedy with extraction of NAPL through wells.

DEQ Response:
The text has been changed to state: "The results of the cost-benefit analysis and CSM NAPL mobility calculations suggest that the current condition is the most feasible alternative." As discussed above, the ITE was not intended to evaluate the protectiveness of the technologies. Also, as discussed previously, DEQ does not believe the limited NAPL sheens observed this past summer are attributable to NAPL migration from upland source areas. Rather, we believe these sheens resulted from isolated "pockets" of residual or near-residual NAPL located within the contaminated sediments beneath the sediment cap. Implementation of innovative technologies to recover upland sources of NAPL would have no effect on NAPL within the contaminated sediments.

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